TECHNICAL MANUAL

# ORIENTATION FOR ARTILLERY

CHANGES }

WAR DEPARTMENT
Washington, D. C., 19 February 1945

25, 30 June 1944, is changed as follows:

**Designation Grid.**

*a*. Aerial photographs are * * * distance or azimuth. For convenience, the dimension of the grid square is **1.44** inches; the **1:25,000** scale may then be used for determining and plotting the coordinates of points.

*b*. The point designation grid may be printed on the photo (as is the case with the wide-angle photo, fig. 49) or, for photos without the grid a transparent template with the grid printed on it—**the point designation grid template**—may be used. It is essential that all concerned place **the grid or template** on the photo in exactly the same manner. **For vertical photographs the usual procedure is: turn the photograph so the marginal information, whether printed at top or at bottom, is in the normal reading position. The bottom of the photograph then is the edge nearest you. Draw the grid line AA through the fiducial marks at top and bottom of the photograph. Fiducial marks are also known as collimation marks. Draw the grid line MM through the fiducial marks on the sides. The intersection of these lines is the center of the photograph. Additional grid lines are drawn parallel to AA and MM at 1.44 inch spacing. Those parallel to and above MM are lettered NN, OO, PP, QQ, etc. Those parallel to and below MM are lettered ZZ, YY, XX, WW, etc. Lines to the right of AA are lettered BB, CC, DD, etc., and those to the left** ... **JJ, II, etc. When an oblique photograph is used, it** ... **in the normal *photo-reading position* and grid lines** ... **d as described above.**

... etermine the * * * the fire-control grid. For example, using a **1:25,000** scale to the nearest ten yards, the coordinates of the point in figure 50 are KN7763. If less accuracy is sufficient, the coordinates are KN86.

[AG 300.7 (14 Feb 45).]

AGO 412C—Feb. 622703°—45

BY ORDER OF THE SECRETARY OF WAR:

OFFICIAL:
J. A. ULIO
*Major General*
*The Adjutant General*

G. C. MARSHALL
*Chief of Staff*

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For explanation of symbols, see FM 21-6.


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TM 44-225
C 1

TECHNICAL MANUAL

# ORIENTATION FOR ARTILLERY

CHANGES No. 1 }

WAR DEPARTMENT,
WASHINGTON 25, D. C., 2 November 1944.

TM 44-225, 30 June 1944, is changed as follows:

* * * * * * *

*b.* A scale could * * * as an indicator. **Figures 9 to 17, inclusive, illustrate the construction and method of reading a vernier.**

## 39. Stadia

*a.* The stadia is * * * is not required. For this purpose two additional horizontal hairs, called stadia hairs, are carried in the transit telescope on the same **reticle** as the cross hairs and are placed equidistant from the horizontal hair.

* * * * * * *

## 58. Types of projections

* * * * * * *

*c.* POLYCONIC PROJECTION.

* * * * * * *

(3) A map prepared in this way shows very little distortion for narrow areas (east to west), the maximum error in a map whose width is 10° east to west being about **0.22** of 1 percent. This is smaller * * * figs. 30 and 31.)

* * * * * * *

## 65. Determination of grid coordinates

...g sin...ral * * * of a point:

* * * * * * *

...ersion of geographic coordinates to military grid co-...ates by *formula* is explained in paragraph 117*f*, TM 5-235.

* * * * * * *

## 70. Computation of grid azimuth and distance

* * * * * * *

*b.* $\Delta y$ CORRECTIONS. The azimuth and * * * of scale error. The error of the polyconic projection is a result of projecting a

curved surface onto a plane. (See figures 43 to 47, inclusive.) The correction for * * * is being used.

* * * * * * *

## 99. Measurement of angles

* * * * * * *

*b*. In figure 62 * * * at each station.

* * * * * * *

(3) Plunge the telescope * * * left of sight. Then, *using the upper motion only*, direct the telescope on the next station *C* and record the reading of **vernier** *A*. If the station * * * by the recorder.

* * * * * * *

## 102. Example of field notes

*a*. Traverse from No. 7 to gun directing point (*DP*) military grid coordinates of No. 7: $X=675{,}578.0$

$Y=1{,}580{,}779.5$ Zone "A"

Latitude 37° 00′ N. Longitude 76° 18′ 24″ W.

* * * * * * *

## 106. Calculation of $\triangle X$ and $\triangle Y$

* * * * * * *

*b*. Take the first * * * in this quadrant. The equation in this quadrant shows that

$$+\triangle x=D\sin B$$
$$-\triangle y=D\cos B$$

* * * * * * *

## 115. Solution of problem—Azimuth and length of base line known

* * * * * * *

*b*. Given the coordinates * * * $=89°30'$.

Length of line *A* to *P* is, by the law of sines:

$$AP=\frac{\text{distance } AB}{\sin \text{ angle } APB}\times \sin \text{ angle } ABF$$

and the length of line *B* to *P* is

$$BP=\frac{\text{distance } AB}{\sin \text{ angle } APB}\times \sin \text{ angle } BAP$$

By logarithms:

Distance *A* to *P*:

Log $A-B=2.03371$

* * * * * * *

## 120. Problem

* * * * * * *

I. Length and azimuth of *BA*

* * * * * * *

$$\text{azimuth} = 125°06'49''$$
$$(180° - \text{bearing})$$
$$BA = \Delta x / \sin \text{bearing}$$
$$\text{Log } \Delta \mathbf{x} = 3.29026$$
$$\text{Log sin } 54°53'11'' = \underline{9.91276} \text{ (subtract)}$$
$$\text{Log } BA = 3.37750$$
$$BA = 2385.1$$

II. Length and azimuth of *CA*

| | |
|---|---|
| $X$ of $A$ | $=702762.0$ |
| $X$ of $C$ | $=\underline{698835.0}$ |
| $\Delta \mathbf{x}$ | $= 3927.0$ |
| $Y$ of $A$ | $=974103.0$ |
| $Y$ of $C$ | $=\underline{977302.0}$ |
| $\Delta \mathbf{y}$ | $3199.0$ |

| | |
|---|---|
| Mag. correction | $=\dfrac{.685+.986}{2}=.835$ |
| $\Delta y$ correction | $=.835 \times 3.199 = -2.7$ |
| Corrected $\Delta y$ | $=3196.3$ |
| Log 3927 ($\Delta x$) | $=3.59406$ |
| Log 3196.3 ($\Delta y$) | $=\underline{3.50465}$ (subtract) |
| Log tan bearing | $=0.08941$ |
| bearing | $= 50°51'23''$ |
| azimuth | $=129°08'37''$ |

$$(180° - \text{bearing})$$
$$CA = \Delta x / \sin \text{bearing}$$
$$\text{Log } \Delta \mathbf{x} = 3.59406$$
$$\text{Log sin } 50°51'23'' = \underline{9.88962} \text{ (subtract)}$$
$$\text{Log } CA = 3.70444$$
$$CA = 5063.4$$

* * * * * * *

V. Length *BP*

* * * * * * *

*c.* $\Delta x = BP \sin \text{bearing}$ $\Delta y = BP \cos \text{bearing}$

Log $BP$=3. 42104 Log $BP$=3. 42104

Log sin bearing $= 9.87051$
Log $\Delta \mathbf{x} = 3.29155$
$\Delta \mathbf{x} \doteq 1956.8$
$X$ of $B = 700811.0$
$X$ coor. of $P = 702767.8$

Log cos bearing $= 9.82620$
Log $\Delta \mathbf{y} = 3.24724$
Mag. of $\Delta \mathbf{y} = 1767.0$
scale corr. $(1.767 \times .835) = +1.5$
$1768.5$
$Y$ of $B = 975476.0$
$Y$ coor. of $P = 977244.5$

* * * * * * *

## 121. Comparison of methods

It has been * * * some particular way. If the reconnaissance officer **realizes** the advantage of each method over the other, he is able to work to better advantage in the field.

## 139. Errors

* * * * * * *

*g*. MISTAKES IN RECORDING AND COMPUTING. Transposing figures, recording foresight as backsight or omitting a **fore** or backsight entirely are among the common mistakes. A convenient check on the computations is obtained by the following rule: add all backsights together; add all turning point foresights, including the foresights on the closing point, together; the difference between these **sums** should equal the difference between the elevations of the starting and closing stations.

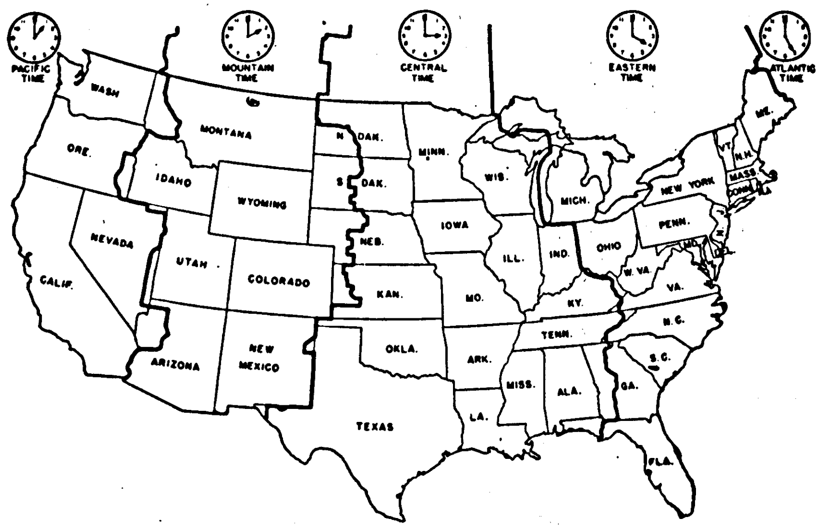


*Figure 106.—Standard time zones in the United States.*

**186. Procedure at culmination**

The transit should * * * minutes of angle.

**199. Procedure**

Set the transit * * * vertical cross hairs. When the star has been bisected **precisely** by both cross hairs at the same time, read and record the reading of the vertical and horizontal scales. Several observations should * * * to increase accuracy.

**206. Computation**

The standard Ageton form * * * entered under the $K$ value. The value of combined $K$ and $\phi$ in the third column is found by adding arithmetically the values of $K$ and $\phi$ if $K$ and $\phi$ are of different signs **or** subtracting if they have the same sign. The $K$ and $\phi$ value * * * on the form.

**211. Example of azimuth determination by solar observation**

**Figure 146** is an example of the complete computations of grid azimuth using the hour angle method, Ageton formulas and tables. For a detailed * * * an erroneous solution.

* * * * * * *

**219. Computation**

The mean values are * * * The computations for the sun observations by the altitude method are based on the formula:

$$\cos \tfrac{1}{2} Z=\sqrt{\frac{\cos S \cos (S-p)}{\cos \phi \cos h}}$$

$Z$=bearing from elevated pole

* * * * * * *

$S=\tfrac{1}{2}(p+\phi+h)=\tfrac{1}{2}(112°53.6'+36°00.0'+20°43.6')=\tfrac{1}{2}(169°37.2')=$ $84°48.6'$

$$\cos \tfrac{1}{2} Z=\sqrt{\frac{\cos S \cos (S-p)}{\cos \phi \cos h}}$$

| | |
|---|---|
| $S=84°48.6'$ | Log cos $S$ = 8.95645 |
| $S-p=84°48.6'-112°53.6'$ | Log cos $(S-p)$= 9.94560 |
| $=28°05.0'$ | Colog cos $\phi$ = 0.09204 |

*WAR DEPARTMENT TECHNICAL MANUAL*

*TM 44-225*

*This manual supersedes TM 4-225, Orientation, 15 July 1941.*



# ORIENTATION FOR ARTILLERY



*WAR DEPARTMENT • 30 JUNE 1944*



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WAR DEPARTMENT,

WASHINGTON 25, D. C., 30 JUNE 1944

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BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
*Chief of Staff.*

OFFICIAL:
J. A. ULIO,
*Major General,*
*The Adjutant General.*

DISTRIBUTION:
As prescribed in paragraph 9a, FM 21–6 except AAA Sch (500); CA Sch (200); FA Sch (200); Bn & H 4, 6, 44 (5); C 4, 6, 44 (3).
For explanation of symbols, see FM 21–6.

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**CHAPTER 9. VERTICAL CONTROL.**



**CHAPTER 10. ELEMENTARY ASTRONOMY.**



**CHAPTER 11. AZIMUTH DETERMINATION—APPROXIMATE METHODS.**



**CHAPTER 12. STELLAR OBSERVATION.**



**CHAPTER 13. SOLAR OBSERVATION.**

*This manual supersedes TM 4-225, Orientation, 15 July 1941.*

# CHAPTER 1

# GENERAL

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## Section I. GENERAL

### 1. Definition

Orientation is defined as any process by which direction is ascertained. When the word orientation is used in connection with artillery, however, it includes the location of points in both a horizontal and vertical direction, and the establishment of lines of known length and azimuth.

### 2. Methods

The methods of solution of an orientation problem are dependent upon the time available for the solution and the equipment at hand. The methods presented in this manual include both quick, approximate methods and more lengthy, precise methods.

### 3. Precision

Precision is the ideal which is sought for in the solution of any orientation problem. However, the time permitted for the solution may not be sufficient to allow the completion of the problem by a precise method. A hasty approximation of direction is far preferable to an uncompleted survey made with a high degree of precision. The greatest precision consistent with the time available must be the goal of all reconnaissance officers.

### 4. Training for survey accuracy

*a.* Precise methods. Use the most precise method the available time permits.

*b.* Checking. Check all work if only by a rough method. Employ completely independent checks by different men when practicable.

*c.* Notes. Watch particularly the preparation of notes; these must be legible, accurate, and clear. More mistakes occur through badly kept notes than through errors in measurements or calculations.

*d.* Procedure. Develop methods and procedure that produce accuracy and eliminate mistakes. Enforce these methods rigidly. Study

---

*Note*: For military terms not defined in this manual, see TM 20-205.

methods for the *weak link*. One inaccurate step will destroy the accuracy of an otherwise precise survey.

*e*. SELECTION OF MEN. Use selected men. Remove men who do not become precise and methodical with reasonable training. A good survey man, like a good gunner, rarely makes a mistake.

## Section II. BASIC METHODS

### 5. Determination of position

Position in the horizontal plane is determined by three basic methods: *traverse*, *intersection*, and *resection*. There is an inclination on the part of the beginner in survey to think of these as three unrelated methods, each an example of survey used under special conditions. As a rule, the beginner never clearly understands why one method is used instead of another. These three methods might be compared to a woodsman's tools, for example, a saw, an ax, and a knife. The saw, ax, and knife are all cutting tools that can be used to clear a woods. The saw is more advantageous to use than the ax under some conditions. The saw and the ax are faster than the knife, but the knife is more precise. The knife might be represented by traverse, the saw by intersection, and the ax by resection. If precision is the main objective and time required is of no importance, the knife (or traverse) might be employed. If speed is essential and there are not too many obstacles, the saw (or intersection) might be used. The completed work may not have quite the high degree of precision but the speed of performance is considerably greater. However, if there are a great number of obstacles, and it is desired to rough out the work fast, the ax (or resection) is used. In survey, the experienced field man uses all three methods in many orientation problems, according to the conditions that are presented. They are not three separate and distinct problems, but are interrelated, and having special advantages for certain work. Traverse is more precise in flat, open country but is slow and laborious. It is especially good for determining position of local points a short distance from a point of known position. Intersection is more precise in a rougher country where certain points are intervisible. It is fast, and can be used advantageously when two known points can be occupied. Resection is more precise in very rough country, is fast, and can be used to advantage when three points of known position can be seen from some other point. Traverse can be used to establish a base line for an intersection problem. Intersection can be used to determine the posi-

tion of a third point and resection may be used to expand the survey, so that other points may be located in position. Traverse then can be used to determine the position of local points around the known points established by intersection or resection. The ax has been used to fell the trees, the saw to cut them up, and the knife to trim the smaller twigs.

## 6. Determination of direction

*a.* The directions of points from some known point are necessary, so that data may be transmitted from one point to another. With the direction to one point known, the direction to other points may be computed from the angles between points, determined in the survey. For a small survey to be used for a small local unit, an initial precise direction may be relatively unimportant. However, if the survey is to be expanded or more units are to be included, more precise direction is necessary.

*b.* The compass may be sufficiently accurate to determine direction for a man on a patrol, or an isolated battery. A direction within one degree may be good for a larger area, or a tie between two batteries, but, for a coordinated defense over a large area, the direction of a point must be determined as precisely as possible, in the time allowed, and with the equipment available. Astronomical methods are used in this case.

## 7. Vertical control

Position in a vertical plane is important to seacoast and field artillery, but normally is relatively unimportant for antiaircraft artillery. However, there will be occasions when the antiaircraft artillery is assigned a mission normally assigned to seacoast or field artillery. Vertical position is then important and methods of leveling must be used.

## 8. Designating location

*a.* After position has been determined for a unit, it is necessary to locate that position in respect to other units, and according to the overall plan of the larger unit. In order to see the overall picture, a position must be tied into a map or aerial photograph so that data may be transmitted from one unit to another. The orientation problem then includes an understanding of maps and their construction.

*b.* A map is necessarily a correct representation of a territory. The accuracy of representation of certain details depends on the method used to construct the map, that is, the type of projection used. One projection gives better results in reproducing certain details of conditions than does another. Therefore, different types of projections are used to show different types of details.

*c.* Location is designated on maps by coordinate numbers. This requires a knowledge of coordinate systems and their advantages.

## 9. Summary

The reconnaissance officer must understand methods of finding position on the ground, determining direction, determining elevation, methods of designating these data on maps, and construction of coordinate systems for transmission of data to other units.

# Section III. SIGNIFICANCE OF FIGURES

## 10. General

When dealing with computations, there is a tendency to lose sight of the accuracy of basic measurements as compared to the computations to be made from these measurements. Often more figures are used in the computations than the accuracy of the original measurement justifies. A measurement made with a foot rule does not justify a computation by logarithms that gives an accuracy in decimals of an inch. Any such computation is a waste of time and gives an erroneous idea of accuracy. A proper balance must be made between precision of measurement and precision of computation.

## 11. Measurements

There are many kinds of measurements, but practically all can be classified as counting separate units, dividing into equal parts or comparison with some unit of measure:

*a.* A person buys 1,000 horses, and if they are carefully counted there is no reason why he should get either 999 or 1,001 horses. In this case 1,000 horses are exactly 1,000 horses, no more nor less.

*b.* (1) Again, this person buys a single piece of cloth containing 1,000 linear yards. He might measure and remeasure the cloth with a yardstick and never get exactly the same measurement twice. These differences in measurements may be caused by not putting the cloth under the same tension each time, by not using the same precision in fitting the yardstick to the successive portions of the cloth, or by an error in the yardstick.

(2) A yard is not a separate and distinct thing such as a horse, but is a comparison to a certain standard. Yardsticks are probably never absolutely correct, but are usually accurate enough for the purpose for which used.

*c.* The dividing of an angle into unit parts is an operation of both dividing and fitting a standard to each part. If the three interior angles of a triangle are measured accurately, their sum will rarely be exactly

180°. This inaccuracy is caused both by the instrument and its use or application.

*d.* Each instrument, tape, or standard gives a certain accuracy when used correctly and for a certain range of measurements. Measurements are only accurate to a certain percentage, depending upon the construction of the instrument with which the quantity is measured, and the way the instrument is used.

*e.* The accuracy of an instrumental observation depends upon the precision with which the instrument was constructed, and the skill, care and personal efficiency of the observer.

**12. Transit observations**

*a.* When using a transit, reading to the closest minute, the reading of measurement of an angle can be expected to be accurate within ½ minute. The graduations of the circle of a transit are very accurate and can usually be depended upon to be more accurate than any reading of the vernier. Consequently, the full value of the instrument is not utilized by single readings of an angle. To obtain a reading of an angle more accurately, it is customary to measure an angle by repetition. By repetition, small excess increments are multiplied so that a total large angle may be divided by the number of repetitions to give a measurement to a finer degree. Angles are usually repeated six times for precise work.

*b.* Little added accuracy is gained by making a very large number of repetitions as there are systematic errors introduced by the action of the clamps and the accuracy apparently gained is really lost on this account. The maximum degree of accuracy that may be expected when using a transit reading to the closest minute, with careful observation is about ten seconds.

**13. Tape measurements**

The accuracy of tape measurement is dependent upon the care exercised in the operation of the tape. With a steel tape, an accuracy of 1 in 5,000 can be obtained without difficulty, if ordinary care is used in plumbing and aligning and if an allowance is made for any considerable error in the length of the tape. For accuracy greater than 1 in 10,000, it is necessary to know the temperature and the tension of the tape when measuring. Also, it is necessary to know the corrections necessary to make allowance for any considerable variation from these values. Therefore, with ordinary care, tape measurements of distances seldom exceed an accuracy of 1 in 7,500.

**14. Significant figures**

*a.* Significant figures are any of the digits actually used to represent an amount or quantity. To secure final results to any given degree of

precision, the measurements in the field must be taken with sufficient precision to yield such results. In computation of data, the computer must determine how many places of figures he must use in the computations, the intent being to obtain all the accuracy which the field measurements or original data yield without wasting time by using more significant figures than are necessary. It is probable that more than half the time expended in computations is wasted through the use of an excessive number of places of figures.

*b.* The number of significant figures in the result of an observation is the number of digits which are known. For instance, if a distance is recorded as 8,100 yards when its value is obtained to the nearest hundred yards only, it contains but two significant figures. The zeros are only to show the place of the decimal point. If, however, the distance is measured to the nearest yard and found to be 8,100 yards, there are four significant figures, for the zeros are here as significant as the 8 or 1.

*c.* Similarly, a measurement such as 0.0052 meter contains but two significant figures; the zeros simply designating the position of the decimal point. Had this same value been recorded in a unit one thousandth as large (millimeters), the result would have been 5.2.

*d.* Again, if a series of measurements is taken between two points to thousandths of a yard and three of the results are 5.284, 6.142, and 5.000, it is evident that each of these distances contains four significant figures; if each one is multiplied by 1.467 the results are 7.752, 9.010, and 7.335 respectively. But had the measurements been taken to the nearest tenth of a yard and found to be 5.3, 6.1, and 5.0, these values when multiplied by 1.467 should appear as 7.8, 8.9, and 7.3. This example indicates the proper use of significant figures. The retaining of more figures than is warranted by the precision of the data is both useless and misleading.

## 15. Logarithms of numbers and trigonometric functions

In deciding how many places or decimals to use in the logarithms of trigonometric functions, the computer examines the tabular differences and determines what percentage error is introduced by any error in an angle. For example, suppose an angle of a triangle is measured in the field to the nearest minute. There may be an error of 30 seconds in this angle, and examination of the table of logarithmic sines shows that the tabular difference for 1 minute in the fourth decimal place, varies from 14 for a small angle, to less than 1 for a large angle, and that the variation is about the same for cosines, and for tangents and cotangents of angles under 45°. Thus for ½ minute the difference is, on the average, about 1 in the fourth place. Therefore, in general, four places are sufficient when angles are measured to the nearest minute only. But, if there are several steps in the computations it may be advisable to use five-place tables. Similarly, five-place tables of functions, in general,

give angles to the nearest 10 seconds, and six-places tables to the nearest second. These are only average results and are intended as a suggestion to the use of four, five, six, or seven-place tables. It is obviously a great saving of time to use five-place tables where five places are needed rather than to use six- or seven-place tables and drop off the last one or two digits. The amount of labor increases about as the square of the number of places in the tables; for example, work with seven-place tables is to work with five-place tables as 49 is to 25.

## 16. Summary

As five-place tables of logarithms give an average accuracy of ten seconds in angular units and as a 1-minute transit cannot give an accurate reading of less than ten seconds by using repetition, it is unnecessary to use more than five-place tables for trigonometric functions for ordinary orientation. Also, as the distances involved in baseline and position computations rarely exceed 10,000 yards, five significant figures are sufficient to determine accurately a base line length to the closest yard. These values are well within the values used as minimum values imposed by limitations of accuracy of present fire control equipment.

# CHAPTER 2

# DUTIES OF RECONNAISSANCE OFFICERS

## Section I. GENERAL

### 17. General duties

The duties of a reconnaissance officer (group, battalion, or battery) are normally divided into general parts as follows:

*a.* The actual reconnaissance in the selection of positions for the various elements of the unit.

*b.* The orientation work necessary to locate the positions selected and to establish an orienting line of known azimuth at each position.

*c.* In AAA units the organization of observation posts and supervision of spotters and observers.

*d.* The preparation of charts, special maps, and sketches.

### 18. Sequence of duties

These general duties cannot be performed concurrently but they are accomplished in the order named. Only that part of the duties of a reconnaissance officer having to do with the orientation work is covered in this manual and is called the orientation problem.

## Section II. SITUATION

### 19. Stability of situation

The amount of orientation performed and the degree of precision to be used must be decided by the reconnaissance officer after making an estimate of the situation and its effect on his unit. A stable situation permits complete coverage of the orientation problem with precise methods. A moving situation may result in very sketchy orientation by rough methods.

### 20. Coordination

The type of orientation depends also on the degree of coordination which is to be effected with adjacent units. For example, an AAA battery operating by itself may need only an orienting line established by compass for the purpose of making corrections for meteorological messages. However, a unit coordinated with adjacent units needs accurate distances between units, precise azimuths, and precise location of battery directing points.

### 21. Mission

The type of orientation performed is dependent upon the mission of the particular unit. For example, when antiaircraft artillery is performing its primary mission in a very mobile situation, time may not permit any complete orientation and coordination with adjacent units even though it is desirable. In static and semistatic positions it is generally possible to perfect the orientation and coordination to a greater degree, dependent on the time available, and physical limitations. Under other circumstances, antiaircraft artillery may be employed as reinforcing field artillery which will require orientation of the type used by the field artillery.

### 22. Estimate

The reconnaissance officer must judge the time permitted for his work, must estimate the degree of coordination that must be maintained with adjacent units, and must anticipate the missions which his unit might be assigned.

## Section III. PREPARATION FOR FUTURE ACTION

### 23. Preparation for an advance

The orientation work of a unit is not completed with the orientation of the various elements. The reconnaissance officer must be prepared to furnish data for the orientation of matériel in an advanced position to be occupied in the future. This future position may be an alternate position, or may be a position at present occupied by the enemy. Methods of intersection and resection can be used in conjunction with aerial photographs and maps to determine the precise location of prominent, well-defined points behind enemy lines. These points can then be used for orientation of matériel after the advance is accomplished.

## 24. Preparation for change of mission

● It may logically be expected to have an artillery unit moved from one locality to another when the mission of the unit is changed. The reconnaissance officer attempts to compile as complete data as possible to permit rapid orientation when the unit is moved. If the prospective mission is known, a survey in the new locality is necessary. If the new locality is not known the orientation work may only be an expansion of control points laterally from the occupied position. This gives the reconnaissance officer several points of known position to use as base points for orientation work in a new position, not too far removed from the occupied position.

# Section IV. ORIENTATION PROBLEM

## 25. Procedure

*a.* It is the duty of the reconnaissance officer to obtain maps, photomaps, or aerial photographs of the area, and to make overlays for the use of interested personnel in his unit. These overlays include any pertinent data such as coordinates of prominent points which can be used for orientation or by the subordinate unit, and existing roads and bridges.

*b.* The plan for conducting the orientation work is made up by the reconnaissance officer who confers with reconnaissance officers of adjacent units if coordination is to be maintained with these units. With this plan in mind, he details the work that is to be performed by the survey party in his detail. The amount of orientation and degree of precision is directly in ratio to the amount of coordination to be maintained with adjacent units.

*c.* The reconnaissance officer is responsible for obtaining the geographic or grid coordinates of any position occupied by his unit. He is responsible for data concerning direction or distance of any point to be used for an orienting point or aiming point and for length of any line to be used for a base line for future orientation or for observation stations.

*d.* The reconnaissance officer is responsible (but will probably detail personnel and advise as to method) for establishing an orienting line and computing parallax for any matériel of a battery for which these data are necessary.

*e.* It is the responsibility of the reconnaissance officer to furnish the coordinates of a ground target if a coordinate system is being used and

the coordinates of the gun battery are known. Otherwise, he may be expected to give the data of range and azimuth to a given target from each battery in his unit. When AAA is employed as reinforcing field artillery it is the responsibility of the reinforced field artillery to conduct the target area survey and furnish a battalion place mark within the AAA gun battalion position area.

*f.* The reconnaissance officer is responsible for obtaining more precise data for orientation as time permits and for preparing data for future locations or alternate positions.

*g.* The reconnaissance officer is required to know the type of orientation being used by adjacent artillery units and to plan his orientation work in such a way that coordination with that adjacent unit can be accomplished, if necessary. This requires that he be familiar with standard procedure in the theater in which he is working, so that he can convert his data to fit to a master plan, as the situation develops. This necessitates the use of the type of coordinate system considered standard for that theater, and requires that direction be determined as precisely as possible, under the conditions presented, so that an expansion of the basic data will not require duplication of work.

## 26. Summary

The reconnaissance officer must provide himself with copies of all maps, aerial photographs, and survey data that may be available for his area. He must anticipate the needs of the situation so that he will have the coordinates of a chosen point and the required orienting line, by the time the information is needed. He must insure that he is conducting his survey in a proper manner to allow expansion, and to permit the joining of his system with that of an adjacent unit, without the necessity of resurveying an area. He must be familiar with foreign maps and systems of coordinates, so that he can transfer data from these maps to his own maps with accuracy. He must be prepared to furnish the geographic coordinates (latitude and longitude) of any occupied point.

# CHAPTER 3

# INSTRUMENTS

## Section I. MISCELLANEOUS EQUIPMENT

### 27. Stadia rod

*a*. The stadia rod is a device used with a transit to determine distances by stadia. It consists of a flat wooden strip 3 to 5 inches wide and usually 10 to 12 feet long. For convenience the rod is made in two sections and hinged. The graduations painted on the rod are in the form of diagrams made so that the 0.05- or 0.10-foot spaces can be easily distinguished and the hundredths of a foot estimated.

*b*. The method of reading the stadia rod is illustrated in figures 1 and 2. The stadia reading is the difference between the readings of the two intercepting cross hairs as viewed through a transit telescope, and not the reading indicated at one line.

### 28. Range pole

Range poles are usually 8 or 10 feet long, round or hexagonal, and about 1 inch in diameter. They are made of wood with an iron point, or of steel rod or tubing. They are graduated in feet, the graduations

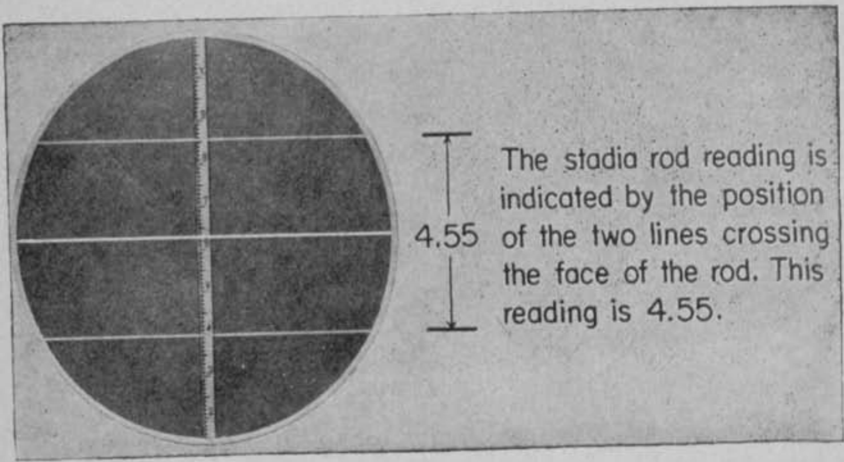



*Figure 1.*

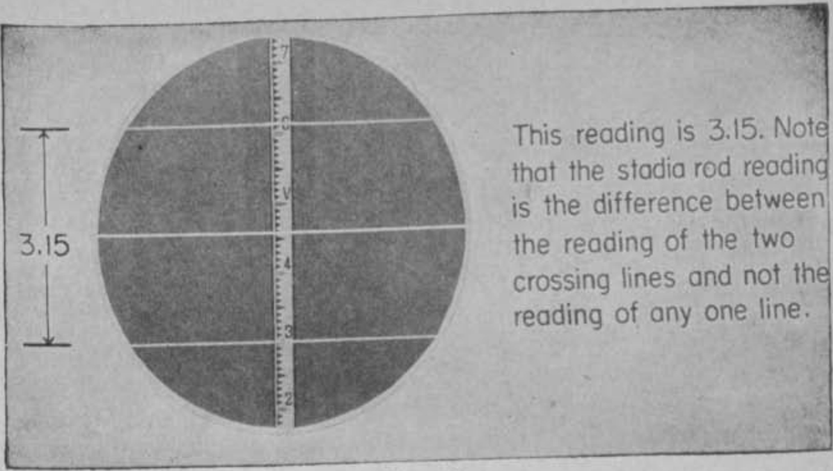



*Figure 2.*

being painted alternately red and white. The range pole is used to mark a point on the ground so as to make it visible from a distance. The sharp point of the pole may be placed in a tack head in a stake. The rod is plumbed by balancing it between the finger tips of both hands, the rodman standing squarely behind it, facing the instrument.

### 29. Steel tape

The steel tape normally issued is a 100-foot tape graduated in feet with the first and last feet of the tape graduated in tenths of a foot. Tapes are sometimes graduated in tenths and hundredths of a foot throughout their length. The steel tape is used for determining distances when precision is desired. Methods of using the steel tape are presented in section IV.

### 30. Plumb bob

The plumb bob is used to transfer a point from one horizontal plane to another. It is used in taping to transfer horizontally measured distance to the ground.

## Section II. TRANSIT

### 31. Use of transit

The transit is used for measuring horizontal and vertical angles, for prolonging straight lines with accuracy, for leveling, and for measuring

distances by stadia. Transits are used for survey work requiring precision in the measurement of angles. They are graduated in degrees with a least reading of 1 minute.

## 32. Description of transit

A complete description of the transit is given in TM 5–235. Figures 4 to 8, inclusive, illustrate the three motions (lower, upper, and vertical) of a transit.

## 33. Verniers

*a.* All transits are equipped with verniers. A vernier is an auxiliary scale used for reading fractions of the smallest division of the main scale. The use of a vernier is based on the fact that it is easier to determine coincidence of two lines than to estimate fractions of a scale interval.

*b.* A scale could only be read to the closest marked division if an indicating arrow alone was used as an indicator. (addition by a1).

## 34. Setting up the transit

*a.* When setting up the transit, place one of the tripod legs in approximately the correct position with reference to the station mark. Then manipulate the other two legs so that the plumb bob is brought over the

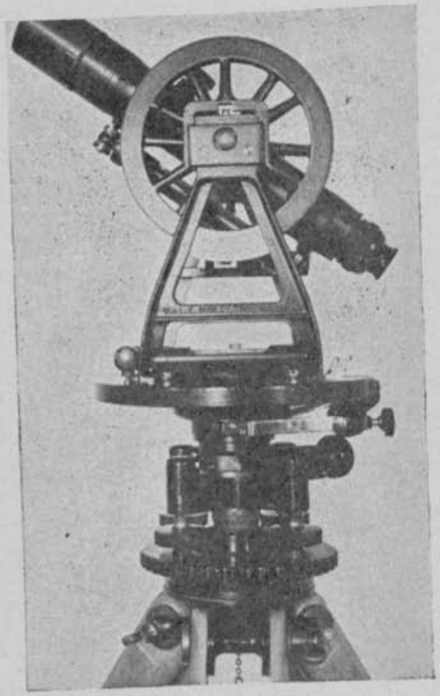


*Figure 3. One-minute transit.*

The lower motion of the transit is used to position the telescope in a horizontal plane without changing the reading of the horizontal scale.

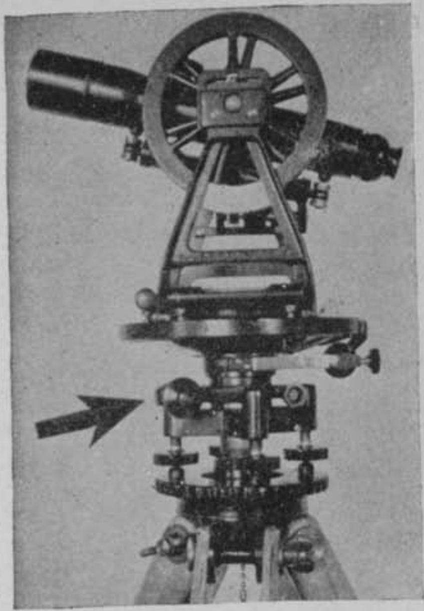


*Figure 4.*

mark, and at the same time the leveling head is approximately level. On hillside, place one tripod leg up hill, the other two down hill. Keep the tripod bolt nuts sufficiently tight so that they will just sustain the weight of the legs when the instrument is lifted. Press the tripod shoes firmly into the ground to insure rigidity. If the plumb bob is nearly

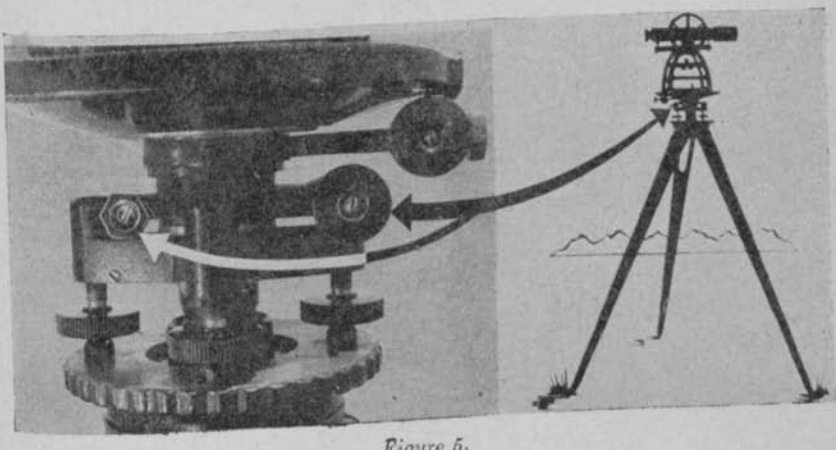
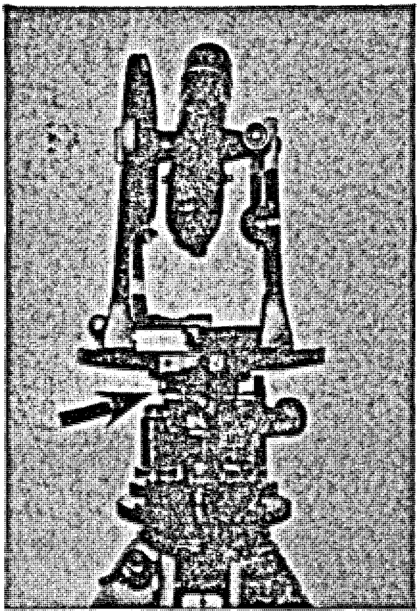


*Figure 5.*

Two means are provided for moving the lower motion. One for preliminary (approximate) setting and a slow motion for final (precise) setting.



The upper motion of the transit is used to position the telescope in a horizontal plane and at the same time move the vernier along the horizontal scale.

*Figure 6.*

over the mark final centering may be made by moving the shifting plate after loosening two adjacent leveling screws. (See fig. 18.)

*b.* When leveling the instrument, turn the plates so that each level of the plates is parallel to a pair of diagonally opposite leveling screws. (See fig. 19.)

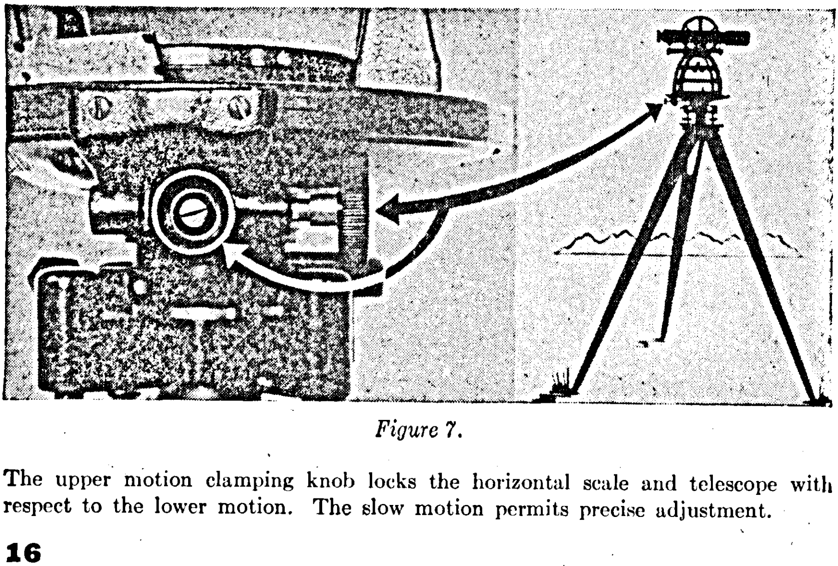


*Figure 7.*

The upper motion clamping knob locks the horizontal scale and telescope with respect to the lower motion. The slow motion permits precise adjustment.

The vertical motion permits positioning of the telescope in a vertical plane. It is provided with a clamp and slow motion adjustment.

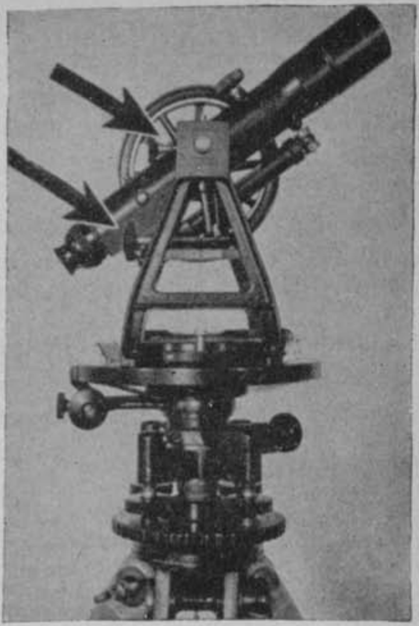
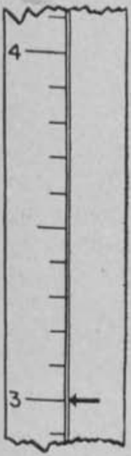


*Figure 8.*

Great care must be exercised when leveling; initially, all screws should have contact with the plate. One or more loose screws will cause the plate to tip and possibly will change the position of the plumb bob over the mark. The screws must not be too tight as this injures the instrument and strains the metal, thereby causing errors. To level, grasp one pair of opposite screws between the thumbs and forefingers and




To construct a vernier on a straight scale.

Take the distance subtended by nine divisions on the scale as the length of the vernier.

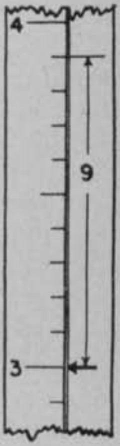



*Figure 9.*

*Figure 10.*

turn so that the thumbs move toward each other or away from each other (see fig. 20), thus tightening one screw and loosening the other. The motion of the two screws must be uniform to prevent binding; one screw descends as fast as the other ascends. After one bubble has been brought nearly to the center of its tube, the other bubble is centered in a similar manner. Instead of getting one bubble centered exactly, it is better to get both bubbles approximately centered, after which one bubble and then the other may be exactly centered. After the instrument is leveled, check the plumb bob to see that it has not been moved from the mark during the leveling process.

## 35. Measuring horizontal angles

*a.* With the instrument set up over the station at which the angle is to be read, set the zero of the vernier opposite the zero of the horizontal

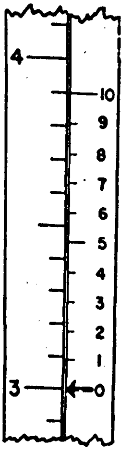



Figure 11.

Make one end of vernier the index, and divide the length of the vernier into 10 equal parts.

The vernier is read by finding the line that most nearly coincides with a line on the main scale, in this case, 5.

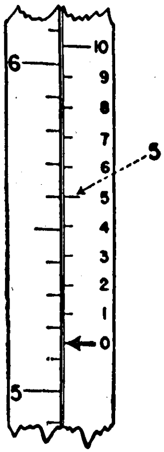



Figure 12

circle, using the upper clamp and slow motion screw to bring them to coincidence. Using the lower motion, point approximately at the first object by looking over the top of the telescope. Move the telescope until the vertical cross hair is very nearly on the point, clamp the lower plate by means of the lower clamp thumbscrew, and set exactly on the point by the lower slow motion screw. The line of sight is now on the first object. To measure the angle, loosen the upper clamp, turn the telescope to the second point, set approximately on the point, clamp the upper plate, and set the vertical cross hair exactly on the point by the upper slow motion screw. The angle is then read, using the vernier which was set at zero. Never overrun the point in bringing the vertical cross hair upon it. Bring the cross hair to the point in such a manner that the slow motion screw compresses the spring against which it works. This eliminates lost motion in the plates.

The whole reading is 5.15 as the vernier has enabled the reading of the scale to 1/100 of the main scale.

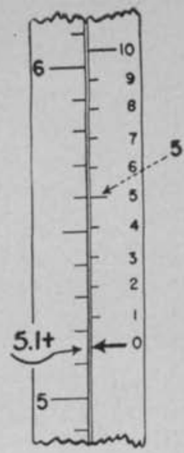



*Figure 13.*

*b.* A complete measurement of any angle consists of the mean of two readings, one with the telescope direct and one with it reversed. The angle is first measured as described in *a* above. The telescope is plunged ("plunging" is reversing the telescope by turning it about its horizontal axis so that the level tube is above the telescope rather than below) and, using the *lower motion only* the first object is sighted upon. Using the upper motion the telescope is then set exactly on the second object. The reading on the vernier which was originally set at zero now gives twice the value of the angle desired. This method takes out most of the errors of instrumental adjustment. (See par. 99 for further details.)

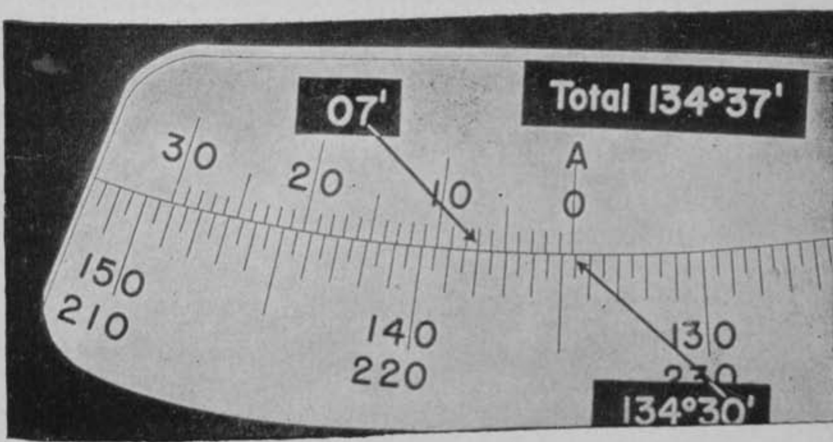



*Figure 14.*

The transit vernier is constructed in the same way as the simple scale vernier. The reading of this scale is 134° 30′ as indicated by the index. The vernier reads 07′. The total reading is 134° 37′.

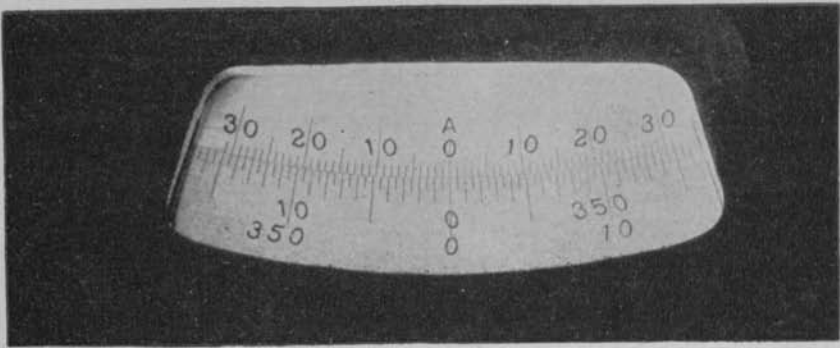



*Figure 15.*

The scale on the transit has two verniers at each index to make reading possible in either direction of turning of the telescope.

## 36. Angles by repetition

The mean of a number of measurements of an angle gives a value of the angle more nearly accurate than any angle measurement. As a minimum, one direct and one reversed reading must always be made. In any case, the same number of direct and reversed readings are made. The direct readings are first made cumulatively; the telescope is plunged and, after sighting back on the first object with the lower motion, the reversed readings are made cumulatively. If, for example, there were three direct and three reversed readings the value of the angle read on the

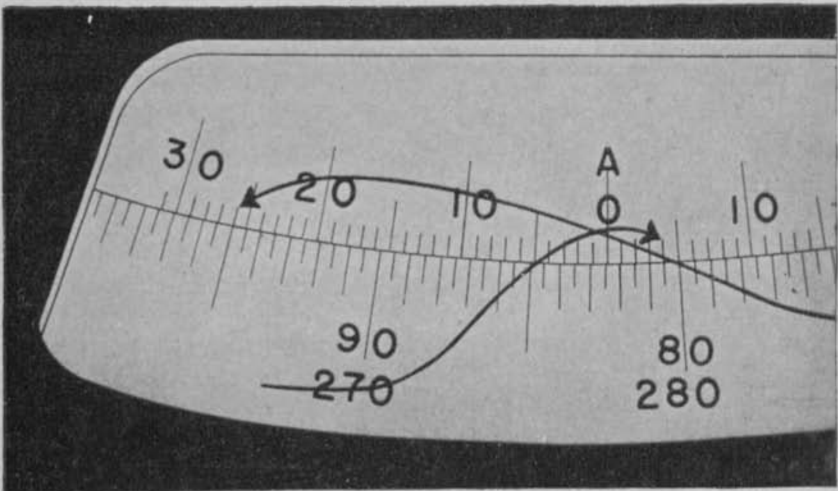



*Figure 16.*

The vernier used in any reading is the one in advance of the index in the direction of turning of the telescope.

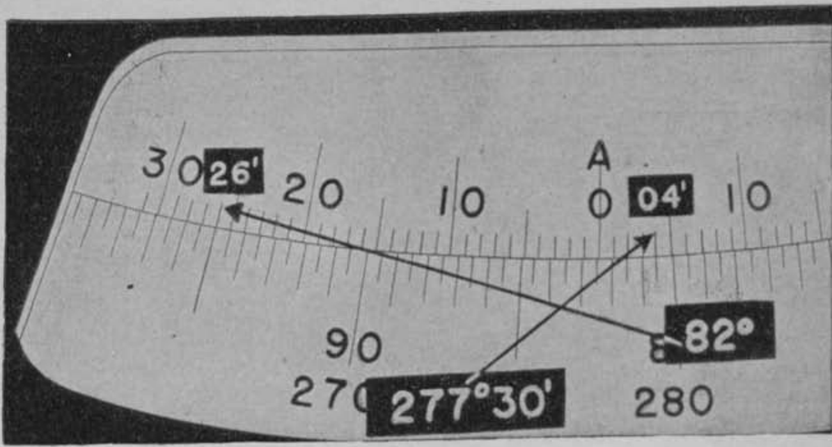



*Figure 17.*

The reading of the scale in this setting is 82° 26′ or 277° 34′. The angle measured will be obvious in a field problem.

vernier is six times that of the desired angle (add multiples of 360° if necessary). Measurement of an angle more than six times will not increase the accuracy of reading of an angle, as the mechanical errors introduced by action of the clamps will offset any increased accuracy that might be expected by additional readings.

## 37. Measuring vertical angles

There are two methods of measuring a vertical angle:

*a.* First method. Set up and level the transit and, using the vertical crosshair, sight upon the distant point; turn the telescope until it is approximately horizontal; clamp; and with the slow motion screw, center the telescope bubble accurately. If the vertical arc vernier reads zero, there is no index error; if not, read and note the angle for the index correction, which must be applied with proper sign to the observed vertical angle. Next sight on the distant point and read the vertical angle. To determine the angle of elevation (or depression) between two points, it is necessary to take into account the height of instrument and the height of target on the rod at the distant point.

*b.* Second method. Level the horizontal plate accurately. Sight on the distant point with the telescope direct (using the middle horizontal crosshair), and read the vertical angle. Plunge the telescope, rotate the instrument in azimuth 180°, sight upon the point, and read the vertical angle again. The mean of the two readings is taken.

## 38. To run or prolong a straight line with transit

*a.* To run a straight line between two points which are mutually visible, set up over one point *A* (see fig. 21), and sight on the other

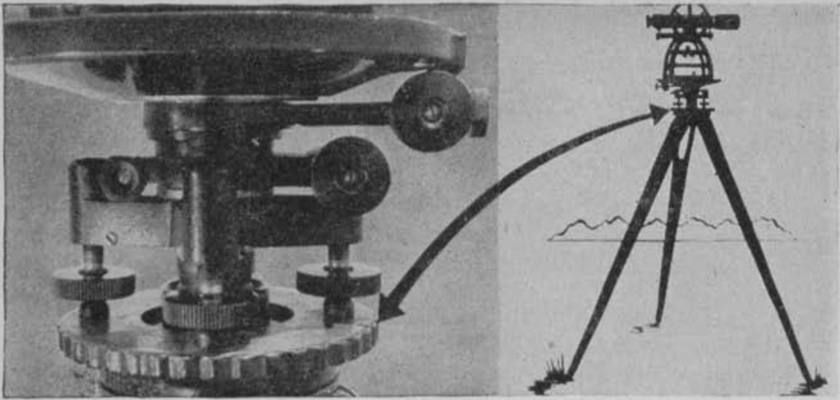


*Figure 18. Leveling plate of a transit.*

point *B*. This establishes the line, and any number of intermediate points or visible points beyond *B* may be set in this line of sight.

*b*. If the two points between which a straight line is desired are not mutually visible, set up as nearly as possible on the line between them and at such a point that both are visible from the instrument. For example, in figure 21, *D* is not visible from *A*. However, if the instrument is set up at *P*, both *A* and *D* are visible. Set up the instrument at *P* and as nearly on line as may be judged by eye. Sight on *A*, plunge the telescope, note how much this trial line varies from *D*, and estimate how far the instrument must be moved sideways to make the prolonged line hit *D*. A point on the line is finally found by successive approxi-

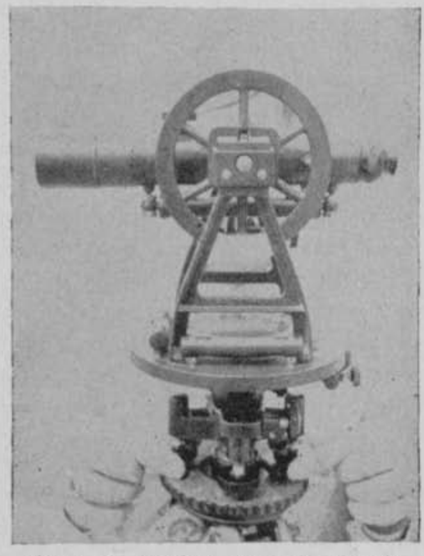


*Figure 19. Method of leveling transit.*

**To level the plate, two opposite screws should be turned at the same time in the manner shown; the bubble will then follow the direction of the left thumb.**

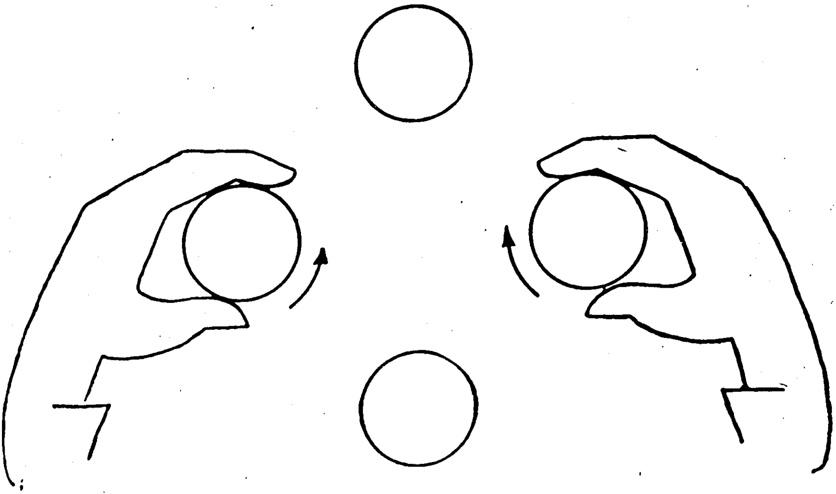


*Figure 20. Direction of turning of screws.*

mation. This is a slow process; to acquire aptness requires considerable practice on the part of the operator.

*c.* To prolong a line from two points, the method in *a* above can be used if the prolongation of the line is visible from *A*. If the prolongation of the line is not visible from *A* (fig. 21) set up over *B*, sight at *A*, and plunge the telescope. The vertical cross hair now will prolong the straight line if the instrument is in adjustment, and points *C* and *D* may be set in on the continuation of the line. If the transit is not in adjustment, set out the points *C′* and *D′* on the new line, rotate the plate 180°, sight again on *A* and plunge as before, setting new points *C″* and *D″* on the continuation of the line. Equidistant between the point *C′* and *C″* and between *D′* and *D″* will be found the true points *C* and *D* of the straight line.

## 39. Stadia

*a.* The stadia is a device for measuring distances by reading an inter-

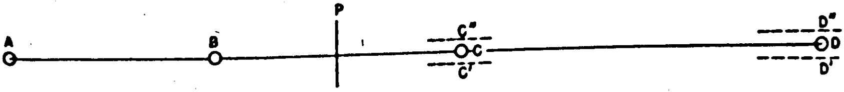



*Figure 21. Prolongation of a line.*

cept on a graduated rod. It is used when great precision is not required. ~~For this purpose two additional horizontal hairs, called stadia hairs,~~ are carried in the transit telescope ~~on the same rectile~~ as the cross hairs ~~and are placed equidistant from the horizontal hair.~~

*b*. USE OF THE STADIA. The transit is constructed with its lower and upper stadia hairs so placed that the intercepted part of the rod, multiplied by 100, is equal to the distance between the instrument and the point on which the stadia rod is read; for example, a reading between the upper and lower stadia hairs of 3.45 feet on the rod corresponds to 345 feet on the ground.

*c*. VERTICAL ANGLES. (1) To determine the horizontal distance and the difference of elevation between points by stadia, the vertical angle is usually read to the nearest minute. With the center horizontal hair set on the rod at the height of the instrument, the reading on the vertical arc gives the vertical angle. The difference of elevation may be computed by using the formula—

$$\text{Difference of elevation} = D\ \tfrac{1}{2} \sin 2A$$

The horizontal distance may be computed by using the formula—

$$\text{Horizontal distance} = D \cos^2 A$$

In the above formulas, $D$ is the stadia reading corrected by the constants and $A$ is the vertical angle.

(2) For field work, stadia tables and a stadia computer are used to compute horizontal and vertical distances. Stadia reduction tables are presented in table VI, TM 5–236.

## 40. Stadia costants

The stadia constants are $K$ and $(c + f)$.

*a*. Since it is difficult to place stadia hairs exactly, many instruments read "long" or short." This difference is expressed by a factor called $K$.

*b*. $(c + f)$ is a correction to be added to each stadia reading: $f$ is the distance from the objective lens to the cross hairs and $c$ is the distance from the objective lens to the center of the instrument. $(c + f)$ is usually given by the instrument maker; if not, it easily can be determined by measuring along the outside of the telescope.

*c*. $K$ is determined by the following formula: $D = KS + (c + f)$, where $D$ is the true horizontal distance and $S$ is the stadia distance. In determining $K$, several distances may be measured and the mean of the values of the several $K$'s may be used. The theory of the stadia is completely explained in TM 5–235.

## 41. Leveling by transit

The transit is equipped with a striding level placed directly below the telescope. The telescope may be clamped in a horizontal position and the transit can be used as a level for spirit leveling in determining elevations.

## Section III. OBSERVATION INSTRUMENT, AA BC, M1 (BC TELESCOPE) AND DIRECTOR

### 42. Use of observation instrument AA BC, M1

The observation instrument AA BC, M1 (BC telescope) is designed for use in recognizing possible aerial targets and as a spotting instrument. It may also be used in lieu of a surveyor's transit for orientation work. Means are provided for measuring horizontal angles to the closest 1/10 mil and vertical angles to the closest 1 mil. No provision is made for the use of stadia.

### 43. Movements of the observation instrument AA BC, M1

*a.* Horizontal movement. The telescope of the instrument is turned in a horizontal direction by a worm gear drive. This worm gear is provided with a throwout lever which permits positioning the telescope in an approximate direction without operating the worm gear. A coarse indicator of azimuth, graduated to the closest 10-mil interval, is provided on the horizontal plate. A fine indicator is provided on the micrometer attached to the operating handle of the azimuth worm drive. The micrometer is graduated at intervals corresponding to 1/10-mil motion of the telescopes in azimuth.

*b.* Vertical movement. Motion of the telescopes in elevation is obtained by means of the elevating worm driven by a knob and engaging with a worm wheel segment. Coarse indications of the vertical angle are obtained from the elevation scale read opposite the adjustable index. This scale is graduated at 100-mil intervals. Fine indications are obtained from the micrometer read opposite its index. This micrometer is graduated at 1-mil intervals. For further information on the BC telescope, see TM 9–1665.

### 44. Telescopes

The observation instrument is provided with two telescopes, the main telescope having a magnification of 10- or 20-power and the elbow telescope having a magnification of 8-power. Each telescope is provided with colored filters that may be introduced to reduce glare, and a means of illuminating the reticle for night observation.

### 45. Survey methods using observation instrument AA BC, M1

Survey methods using this instrument are similar to the methods used with the transit. The results of a survey are not as precise however, since the reticle in the BC telescope has mil readings etched on the glass to form a vertical and horizontal line rather than using cross hairs as in

the transit. This introduces small errors in alignment that would be improbable with a transit. There is no provision for locating the instrument directly over a point by a plumb bob as is provided with the transit so that small errors may be introduced by displacement from a precise point. As the angles measured are indicated in mils the survey must be conducted with angles measured in mils or the angles converted to degrees and minutes.

### 46. Use of director as a survey instrument

In case of necessity, the director may be used to measure horizontal or vertical angles. Horizontal angles are indicated on the present azimuth dials. The coarse indicator indicates angles to the closest 100 mils and the fine indicator to the closest 5 mils. A reading of 2 or 3 mils may be estimated. A vertical angle is indicated on the present angular height dial. The coarse indicator is graduated in 100-mil increments and the fine indicator is graduated in 5-mil divisions. A reading of 2 or 3 mils may be estimated. The weight of the director precludes its use as a survey instrument except to a limited degree.

## Section IV. TAPE MEASUREMENT

### 47. Horizontal taping

*a.* METHOD. The tape is held in a horizontal plane while the measurement is being made, the elevated end being projected to the ground by use of a plumb bob held in the hand of the tapeman. The distance that can be covered by a single measurement by this method is limited by the slope of the ground. A man cannot hold the tape above shoulder height, put the required pull on the tape, and hold the plumb bob steady enough to make an accurate measurement. Therefore, on steep slopes the taping must be done in short sections. This is known as "breaking tape."

*b.* ADVANTAGES. The advantages of this system are that no corrections need be applied to the measured lengths and no instruments are required except the tape and plumb bobs.

*c.* DISADVANTAGES. The disadvantages of this system are that it is sometimes difficult to determine the true horizontal plane, in windy weather the handling of the plumb bob may be difficult causing very slow progress, and a fractional tape length may be easily dropped or misread.

## 48. Slope taping

*a*. METHOD. The tape is stretched along the ground and a full tape length is measured each time. The slope of the tape must be determined and a correction applied to reduce the measured length to horizontal distance.

*b*. ADVANTAGE. This method is rapid, the chaining pin may be set directly under the tape graduations and the tape is generally protected from the wind.

*c*. DISADVANTAGES. The slope of the tape must be determined either from the difference in the elevations of the tape ends or by measuring the angle of inclination of the tape. The slope corrections must then be determined and applied to the measured distance.

## 49. Precision of taping

The precision of taping in artillery survey varies according to the use to be made of the particular measurement. The degree of precision needed may be determined by consideration of the effect on the accuracy of firing data.

*a*. In the measurement of a long base line, the tape ordinarily is leveled by eye and measurements of fractional parts of a foot are made to the nearest tenth.

*b*. A short base line measurement usually must be more accurate; horizontal measuring requires an accurately leveled tape, accurate plumbing, and readings to a fraction of a foot; for slope measurements the angle of slope is carefully read and corrections applied.

*c*. In the ordinary traverse for the purpose of determining the locations of batteries with relation to some selected point, leveling the tape by eye and estimating the tenths in fractional measurements is satisfactory. The precision required depends to some extent on the nature of the traverse. If a traverse is very long, or if it consists of many short lengths, the taping must be done with the same precision used for short base line measurements.

## 50. Taping methods

*a*. ALIGNMENT. Alignment of the tape during the measuring is usually done by the tapemen themselves without help from the instrument man. If the next station has been selected, it is marked by the rodman; the rear tapeman lines the head tapeman in by eye. When the course to the next station is selected before the station is established, the direction of the course habitually should be toward some unmistakable object. The rear tapeman then lines the head tapeman in on the selected course. During the crossing of low ground, it may be necessary for the head tapeman to line himself in with the rear tapeman and the last station.

*b.* Tension and sag. With the tape resting on the ground, a pull of approximately 12 pounds (measured with a spring balance) must be exerted for precise measurements. When the tape is suspended in the air for plumbing, the tension should be increased to remove the sag. An unsupported length of about 100 feet requires a pull of about 25 pounds. Unsupported lengths greater than 100 feet must not be used in a precise survey due to the errors introduced in measurements.

*c.* Fractional readings. Taping usually is done with the zero end of the tape forward. If each foot of the tape is graduated, the head tapeman holds the zero on the forward point while the rear tapeman reads the distance to the nearest one-tenth or one-hundredth of a foot, depending upon the accuracy desired. If only the end feet of the tape are graduated, the head tapeman holds the zero mark short of and within a foot of the forward point, while the rear tapeman reads and calls out the measurement in feet; the rear tapeman then slacks the tape 1 foot, holding the new foot mark accurately over the rear point; the head tapeman measures the fraction of a foot, reading *backward* on the graduations of the first foot of the tape. He announces the total distance, and both tapemen enter it in their notebooks.

*d.* Breaking tape. Measurement by breaking tape is done as follows. The head tapeman pulls out such lengths of tape as can be stretched horizontally. Except for a very short section, the elevated end should not be held above shoulder height. The head tapeman should make the break so that the rear tapeman can hold at a 10-foot mark. For a precise survey, leveling of the tape is done with a hand level by the head tapeman when the course is going down hill, and by the rear tapeman when it is running up hill. For a less precise survey, leveling the tape by eye is satisfactory, particularly when assisted by the view of a distant horizon. The mark on the end of the tape section that is not in contact with the ground must be held accurately, by means of the plumb bob, over the point marked or to be marked on the ground. The head tapeman marks each break with a chaining pin. An alternate method of breaking tape, particularly suitable for the 100-foot tape, is to drag the tape forward its full length. The head tapeman then comes back to a 10-foot mark which permits a section at the rear end of the tape to be horizontal. He marks the measurement on the ground. The rear tapeman then comes forward and holds the same 10-foot mark over the indicated point. This method permits the recording of only complete tape lengths during the breaking of the tape; intermediate points are not marked with the chaining pins.

## 51. Duties of tapemen

*a.* Head tapeman. The head tapeman points out to the rear tapeman the line of the next course; pulls out the tape to the limit allowed by the slope of the ground; determines the necessary height to level the

tape when running downhill; exerts the proper tension on the tape; and calls "Ready." When he hears "All right here" from the rear tapeman, he marks the spot with a chaining pin if his end of the tape is on the ground, or, if the course is running downhill, he releases his plumb bob string and marks with a chaining pin the spot where the point of the plumb bob falls. As soon as he completes the measurement he calls "All right." He leaves a chaining pin at each point. On reaching the end of the course he measures to the station mark, or, if the station has not been established, he sets the station mark.

*b.* REAR TAPEMAN. The rear tapeman aligns the head tapeman. When the head tapeman calls "Ready," the rear tapeman, if his end of the tape is on the ground, holds the proper tape graduation exactly on the pin on the ground and calls "All right here." He continues to hold his end of the tape accurately in place until the head tapeman calls "All right." He recovers the chaining pin which the head tapeman has used in marking the points on the ground. At the end of each course he counts the pins he has collected and sees that the number corresponds to the number of measurements recorded. When the course is running uphill, he determines the lengths of the breaks which can be made, and is responsible that the tape is held level. He uses the plumb bob for holding the proper graduation of the tape over the mark on the ground.

*c.* TAPEMEN'S NOTES. Both tapemen keep independent records of all measured distances. At the end of each course, each tapeman adds the measurements and records the total distance in his notebook before comparing his results with those of the other tapeman. When they do not agree, the course must be retaped. No erasures should be made; a single line should be drawn through an erroneous figure, and the correct figure should be written immediately above or below it.

## 52. Training of tapeman

*a.* TRAINING. Tapemen must be carefully trained in the proper procedure. Prescribed methods must be rigidly enforced. Tapemen must exercise constant vigilance to avoid errors and blunders. The most common blunders are misreading the tape and losing a complete tape length or a plumbed section.

*b.* DON'TS FOR TAPEMEN. (1) Don't jerk the tape.

(2) Don't pull the tape when it is kinked.

(3) Don't let vehicles run over the tape.

(4) Don't bend the tape sharply around corners.

(5) Don't split hairs in lining in.

(6) Don't allow the chaining pin to be disturbed.

(7) Don't pull the pin until you are sure that it will not be needed again.

(8) Don't break tape oftener than necessary. Each break slows up the work and introduces another chance for error.

(9) Don't fail to wipe the tape clean and dry before putting it away.

(10) Don't forget that methodical procedure prevents errors and makes speed.

# CHAPTER 4

# METHODS OF DESIGNATING LOCATION

## Section I. MAPS

### 53. General

*a.* A map is a conventional representation of a portion of the surface of the earth as a plane surface. Since a spherical surface cannot be reproduced as a plane with absolute accuracy, the representation is approximate only, with characteristics dependent upon the projection employed.

*b.* There are many types of map projections, some accurate in one respect, some in another, *but none accurate in all.* It is important that a reconnaissance officer have a general knowledge of their characteristics and know where to get more detailed information when desirable, in order that he may intelligently make use of available nonstandard maps. All available maps of any theater of operations will probably be used by the military forces. Certain types, however, have been found to be best adapted for specific military purposes, and maps are prepared as far as practicable to serve these needs.

### 54. Map classification

*a.* GENERAL. Maps will vary from crude small scale planimetric maps to accurate well-prepared topographic maps suitable for enlargement. They will include various special purpose maps, such as road maps, railroad maps, aeronautical charts, etc. Large scale topographic maps suitable for tactical operations of small units may be expected only in isolated areas of limited size. Except in certain parts of Western Europe, topographic maps to scales as large as 1:20,000 will not be found.

*b.* TYPES OF MAPS. Maps fall into classification according to scale. The use of the various types of maps depends upon the character of the theater of operations, type of operations, and nature of the opposition encountered. Although listed below under various groups of scales for convenience and clarity, maps are normally designated by their specific scales. Designation of maps by general terms descriptive of a range of scales or by purpose or use is not precise and is confusing.

(1) *Small scale maps.* Maps of small scale varying from 1:1,000,-

000 to 1:7,000,000 are intended for the general planning and strategical studies of the commanders of larger units. Various general maps have been designed for these purposes.

(2) *Intermediate scale maps.* Maps of intermediate scale, normally from 1:200,000 to 1:500,000, are intended for planning strategic operations, including the movement, concentration, and supply of troops. The Strategic Map of the United States, 1:500,000 has been designed for these purposes. Maps of a scale of about 1:250,000 are particularly applicable to movements of armored forces and for maps of maneuver areas.

(3) *Medium scale maps.* Maps of medium scale, normally from 1:50,000 to 1:125,000 are intended for strategical, tactical, and administrative studies by units ranging in size from the corps to the regiment. The United States Geological Survey Map, scale 1:62,500, with wooded areas and road classifications added, has been found suitable for these purposes. For strategic areas, the War Department produces maps of this type. While not suitable for all purposes, the scale of 1:62,500 has been found to be the most advantageous for recording topographical detail for future use. For campaign, maps of this scale can be used for the purpose intended or may be enlarged or reduced accordingly to the existing needs.

(4) *Large-scale maps.* Maps of large scale, normally not greater than 1:20,000 are intended for the technical and tactical battle needs of infantry and artillery units. It is unlikely that maps of this category will be found to cover extensive areas. The battle map has been designed for this purpose.

*c.* Aerial photographs. Dependence for topographic information, particularly in the earlier stages of campaign, may have to be placed on aerial photographs, photomaps, or provisional maps. In addition to furnishing information for these maps, aerial photographs are always of value in supplementing information on existing maps. The aerial photograph provides the best obtainable means of securing the latest information of enemy terrain, and the larger scale photographs, particularly when examined stereoscopically, offer detailed information of the terrain which can be secured by no other means.

## 55. Map substitutes

In order to provide a map suitable for technical military use, experiments have been conducted in rapid map making using aerial photographs.

*a.* The vertical aerial photograph is a valuable instrument for conveying topographical information.

(1) It possesses, in picture, a wealth of detail which no map can equal.

(2) It possess accuracy of form.

(3) With freedom of flight, an aerial photograph may be prepared in a short time and reproduced in quantity by lithography.

(4) It may be made of an area which otherwise is inaccessible because of either physical or military reasons.

*b.* The vertical aerial photograph is inferior to a good map in the following respects:

(1) Important military features are sometimes obscured or hidden by other detail.

(2) Neither absolute position nor absolute elevation can be obtained.

(3) Relative relief is not readily apparent.

(4) Displacement of position caused by relief and camera tilt usually do not permit the accurate determination of distance or direction.

*c.* The ideal battle map includes the most accurate topographic map supplemented by the most recent aerial photographs. At the present time, the best known battle map is one which gives control and detail by photogrammetric methods. The multiplex and stereo-comparagraph are used to add contours, grid lines, and battle positions to the map as rapidly as possible to produce the finished battle map.

## Section II. PROJECTIONS

### 56. General

Theoretically the earth is an oblate spheroid in shape; a figure formed by rotating an ellipse around its shorter axis. Because of the continents and islands, the actual surface is irregular. The distance from the center of the earth to a point at sea level on the equator is 3,963.3 statute miles and the distance from the center of the earth to either of the poles at sea level is 3,950 statute miles. This difference is so slight that the earth may be mentally pictured as a round ball or sphere which rotates on a line or axis passing through its center. The imaginary intersections of this axis with the surface of the earth are called the North and South Poles. Circles on the earth's surface, cut by imaginary planes passing through the poles, are called meridians of longitude. Circles cut by imaginary planes at right angles to the axis are called parallels of latitude. The parallel midway between the poles is called the Equator and divides the earth into the Northern and Southern Hemispheres.

### 57. Map projections

*a.* No map is accurate in every detail; if it is accurate in an east and

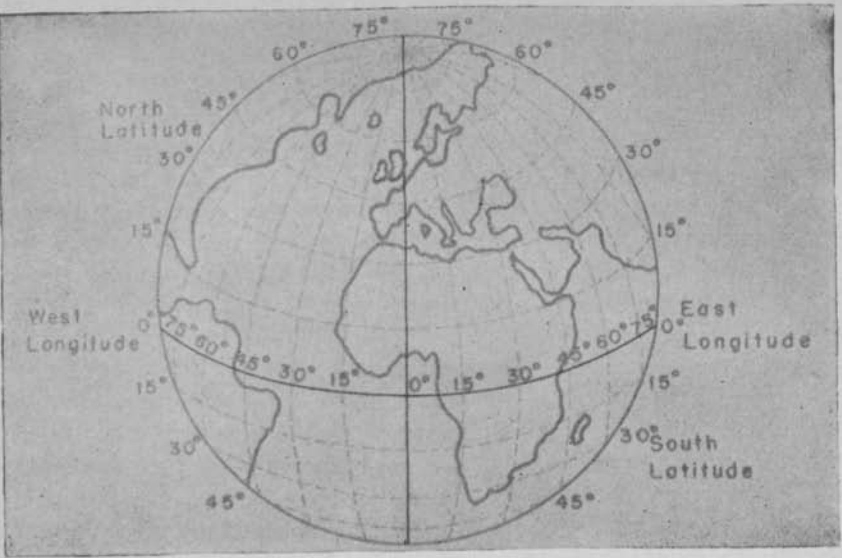



*Figure 22. Origins of latitude and longitude.*

west direction there is distortion north and south, and vice versa. There are many methods of representing a part of the earth's surface approximately and, in determining a method of projection, it is necessary to select one that best meets the requirements the map is to fulfill. The most desirable features of a good map are as follows:

(1) Areas should be represented in their true shape.

(2) Areas should retain their true relative size.

(3) Distances on the map should keep a constant ratio to the same distances on the ground.

(4) Direction of lines and size of angles on the map should be preserved.

(5) Great circles should be represented by straight lines.

No one of these properties can be secured without sacrificing some of the others. In determining the type of projection to be employed, it is therefore necessary to decide which feature most nearly satisfies the conditions under which the map is to be used.

*b.* From a military standpoint, it is desirable to have a projection that gives a minimum of distortion in the representation of distances, and angles at all parts of a map. It is customary in constructing maps to project the portion of the earth's surface under consideration to a cylindrical, conical, or other surface which can be developed into a plane; or to plot it to some system of developed lines which on a plane surface bear homologous relation to the latitude and longitude lines of the earth's surface. It is in this latter category that military maps

belong. Such a system of lines designed for the purpose of constructing a map on a plane surface is called a projection.

## 58. Types of projections

*a.* MERCATOR PROJECTION. The Mercator projection is constructed by projecting radially the meridians and parallels onto the surface of a cylinder which is tangent to the earth at the Equator and then developing this cylinder on the map. The meridians and parallels all appear as straight lines, meridians being equally spaced while the distance between parallels increases toward the poles. The Mercator chart is used to a great extent in navigation, as the bearing between any two points as shown by this chart is the course a vessel would follow to arrive at its destination by steering a constant course. (See figs. 24 and 25.)

*b.* CONIC PROJECTION. In the conic projection, a cone is assumed to be tangent to the middle parallel of the map, the apex of the cone lying in the prolongation of the earth's axis. The cone is developed by first drawing a vertical line as the control meridian of the map. Selecting a suitable point on this line, the slant height of the cone tangent to the parallel of latitude is then laid off on the side toward the pole, thus locating the apex of the cone which serves as the center of a series of circles representing the parallels of latitude. The latter are drawn through points, corresponding to proportional intervals of latitude, previously laid off on the central meridian. After subdividing the middle parallel to correspond to proportional intervals of longitude, straight lines representing meridians are drawn from the apex of the cone to

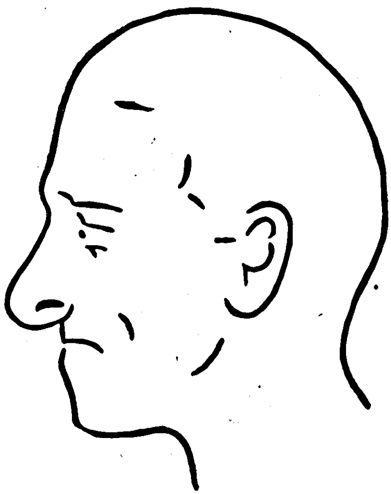


*Figure 23. True picture.*

these subdivisions. The distortions in this projection are so small that it becomes apparent only on maps of very large areas. (See figs. 26 and 27.)

*c.* Polyconic projection. (1) The ordinary, or American polyconic projection, one of the subdivisions of the general division of polyconic projections, has been adopted as standard for all military maps of the United States. Although the polyconic projection is by no means the most accurate or desirable form of projection, it has been adopted because of the comparative mathematical simplicity of construction and the fact that a table for its use has been calculated for the whole earth. In principle the polyconic projection is a modification of the conic projection. Every parallel of latitude is represented on the map by the developed circumference of the base of a right cone tangent to the earth at that parallel.

(2) It is apparent that as the parallels approach the Equator, the shape of the cone approaches that of a cylinder and the Equator appears

*Figure 24. Mercator projection.*

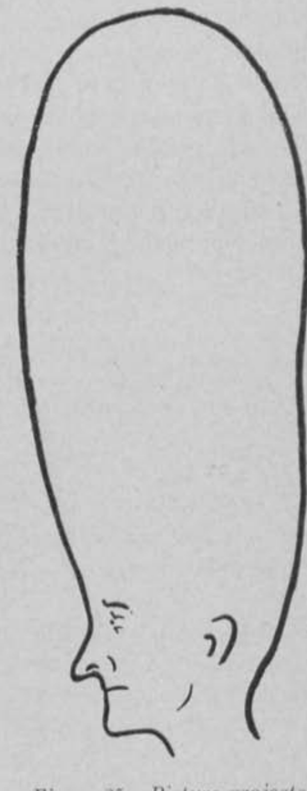


*Figure 25. Picture projected from sphere by mercator projection.*

on the projection as a straight line. The meridian through the center of the area is called the central meridian and is shown as a straight line perpendicular to the Equator. The other meridians are curved lines converging as they go from the Equator toward the poles. The parallels are spaced on the central meridian true to scale and are drawn through these points with the proper radii. Every parallel is then graduated true to scale and the meridians are drawn as curves through the points of equal longitude.

(3) ~~A map prepared in this way shows very little distortion for nar-~~ row areas (east to west), ~~the maximum~~ error in a map whose width is ~~10° east to west being about 1 percent.~~ This is smaller than the expected expansion or contraction of map paper. The polyconic projection is not satisfactory for wide areas (east to west); in a map of the entire United States, the distortion on the east and west edges is as great as 7 percent. On the other hand, no additional distortion is introduced by extending the map north and south. (See figs. 43 to 47.) The length of the map (north to south) may therefore be of any extent. (See figs. 30 and 31.) see c1

*d.* Zone polyconic projection. The only distortion occurring in polyconic projections is in distances running north and south and displaced east or west of the central meridian. It is zero at the central meridian and increases as the distance from the central meridian is increased. (See figs. 43 to 47.) In order that this distortion may be reduced to a minimum on military maps, the United States has been divided for the purpose of projection into narrow north and south zones each 9° of longitude in width. The projection of each individual map or sheet of an area in the zone is represented as a corresponding section

*Figure 26. Conic projection.*

*Figure 27. Picture projected from sphere by conic projection.*

Figure 28. Lambert projection.

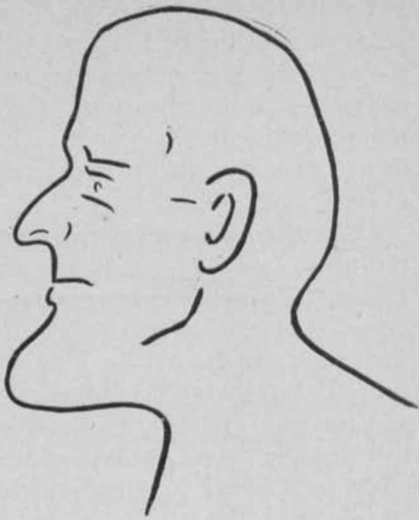


Figure 29. Picture projected from sphere by Lambert projection.

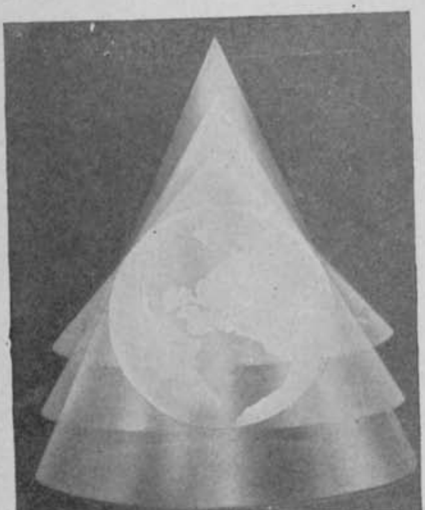


Figure 30. Polyconic projection.

Figure 31. Picture projected from sphere by polyconic projection.

of the zone projection. For convenience in describing the location of points on the map and determining the distance and direction between points, the military grid system has been superimposed upon the zone polyconic projection. The difference between the proper section of the zone projection and a local polyconic projection of the same section is so small that it may be ignored and the local polyconic projection used.

*e.* LAMBERT PROJECTION. (1) Most French and British maps are based on the Lambert projection. The Lambert conformal conic projection is a secant cone type of projection which intersects the earth at two parallels of latitude. Along these two parallels the scale is exact; between them the scale is slightly shortened and outside of the parallels the scale is somewhat too large. This gives a balance of scale over the whole projection and makes it possible to cover a wide extent of latitude with minimum distortion. Tables of scale variations have been computed for every minute of latitude so that these variations may be taken into consideration in any computations and full allowance made for them. Thus computation of distance may be very accurate in all parts of the projection.

(2) When using grid coordinates taken from a Lambert projection for the computation of azimuths and distances, it is not necessary to make any correction for magnification of scale.

(3) The meridians will all intersect at a point at the apex of the cone. When the conical surface is split along an element, it can be unrolled in a plane and the parallels become arcs of concentric circles. When the conical surface is developed in a plane it forms a sector of a circle.

(4) This intersecting type of projection provides a better map than does a tangent cone projection because of its uniformity of scale. (See figs. 28 and 29.)

## CHAPTER 5

# COORDINATE SYSTEMS

## Section I. GEOGRAPHIC COORDINATES

### 59. Reference planes

In order to define positions on the earth's surface it is necessary to have fixed reference planes and surfaces. The surface of mean sea level has been adopted as the surface of zero altitude. The meridian passing through Greenwich Observatory, near London, is usually taken as the reference meridian from which longitude is measured in degrees, minutes, and seconds, halfway around the globe, positive to the west and negative to the east. The Equator is taken as the reference parallel from which latitude is measured in degrees, minutes, and seconds, to the poles, positive to the north and negative to the south of the Equator. (See fig. 32.) Geographic coordinates (latitude and longitude) are used to designate the location of points on the earth's surface by reference to these fixed initial planes. While the algebraic signs of the latitude and the longitude show whether they are north or south, east or west, the letters N, S, E, and W, are usually used, being placed after the figures. For example, the geographic coordinates of the Capitol at Washington are latitude 38° 53′ 23″ N., longitude 77° 00′ 34″ W.

### 60. Foreign maps

Most foreign maps use the Greenwich meridian as the meridian of zero longitude. However, many foreign maps are based on some other meridian as a prime meridian. The Corps of Engineers will usually transfer the given longitudes to standard longitudes based on the Greenwich meridian as the prime meridian when a map is to be reproduced by them. A map issued by some other source must be examined to determine the prime meridian used. Longitude is an inherent part of time computations, so that it is essential that reconnaissance officers be given a source of information for transferring longitude based on one prime meridian over to longitude based on the Greenwich meridian as a prime meridian. The table on page 41 gives the longitude from the Greenwich meridian of the prime meridian used on some maps of the countries listed. Any map used should be checked to determine a discrepancy between standard

longitude and the longitude listed on the foreign map. If a discrepancy is found, the meridian used as a prime meridian should be determined. The correction to transfer to standard longitude may be found in the table following. Any celestial observations made may then be based on standard longitude from the Greenwich meridian.

*Prime Meridian used by Geodetic Section, Army Map Service*

| *Meridian* | *Accepted value* |
|---|---|
| Paris, France | 2° 20′ 13.95″ E |
| Madrid, Spain | 3° 41′ 14.55″ W |
| Monte Mario, Rome, Italy | 12° 27′ 07.06″ E |
| Batavia, Netherlands East Indies | 106° 48′ 27.79″ E |
| Padang, Sumatra, Netherlands East Indies | 100° 22′ 01.42″ E |
| Midden Meridian of S. Sumatra, Netherlands East Indies | 103° 33′ 27.79″ E |
| Ferro, Canary Islands | 17° 39′ 46″ E |
| | (17° 40′ 00″ E used by Germans) |
| Amsterdam, Netherlands | 4° 53′ 01.978″ E |
| Lisbon (Observatory of Castelo de S. Jorge), Portugal | 9° 07′ 54.806″ W |
| Naval Observatory at Genoa, Italy | 8° 55′ 15.929″ E |
| Copenhagen, Denmark | 12° 34′ 40.35″ E |
| Athens, Greece | 23° 42′ 58.5″ E |
| Helsinki, Finland | 24° 57′ 16.5″ E |
| Pulkovo (near Leningrad), U.S.S.R. | 30° 19′ 38.49″ E |
| San Fernando, Spain | 6° 12′ 20″ W |
| Singhawang, China | 108° 59′ 41″ E |
| Istanbul, Turkey | 28° 59′ E (approximate) |

## 61. Parallels and meridians

Parallels and meridians of latitude and longitude are measured by two systems:

*a.* Sexagesimal system (degrees, minutes, and seconds). This is the predominant system and is the system used by the United States. This system is used also by British, Dutch, Chinese, Scandinavian, German, Italian, and Japanese cartographers.

*b.* Centesimal system (grads and decimal fractions thereof). This system is used in France, and by countries whose cartographic practices were influenced by the French. The basic relation between grads and degrees: 100 grads equals 90°. Maps issued to using personnel by the Corps of Enginers will usually be converted to standard longitudes and will be converted to standard systems. However, it is possible to encounter unconverted maps in the field and it is necessary that the reconnaissance officer understand how to convert data.

## 62. Convergence of meridians

*a.* The distance between two adjacent meridians is greatest at the Equator and gradually decreases in a north or south direction until it becomes zero at the two poles. The angular amount by which meridians approach each other is called the convergence of the meridians. For

example, the convergence of the meridian of longitude 72° with that of longitude 73° at the pole is 1°; but at the Equator all meridians are parallel and the convergence is zero. It is thus apparent that the amount of convergence of meridians is a function of the latitude.

*b*. In figure 33, *P* represents the pole, *PA* the seventy-third meridian and *PB* the seventy-fourth meridian. *CD* is a straight line perpendicular to *PA*. At the point *A* where *CD* intersects the seventy-third meridian the true azimuth of *CD* is the angle *PAD*. The azimuth of *CD* at *A* is 270°, that of the same line at *B* is less than 270° by the amount of the convergence of the two meridians.

*c*. The azimuth of the line *BA* is commonly called the back azimuth of the line *AB*. The back azimuth of a line differs from the forward

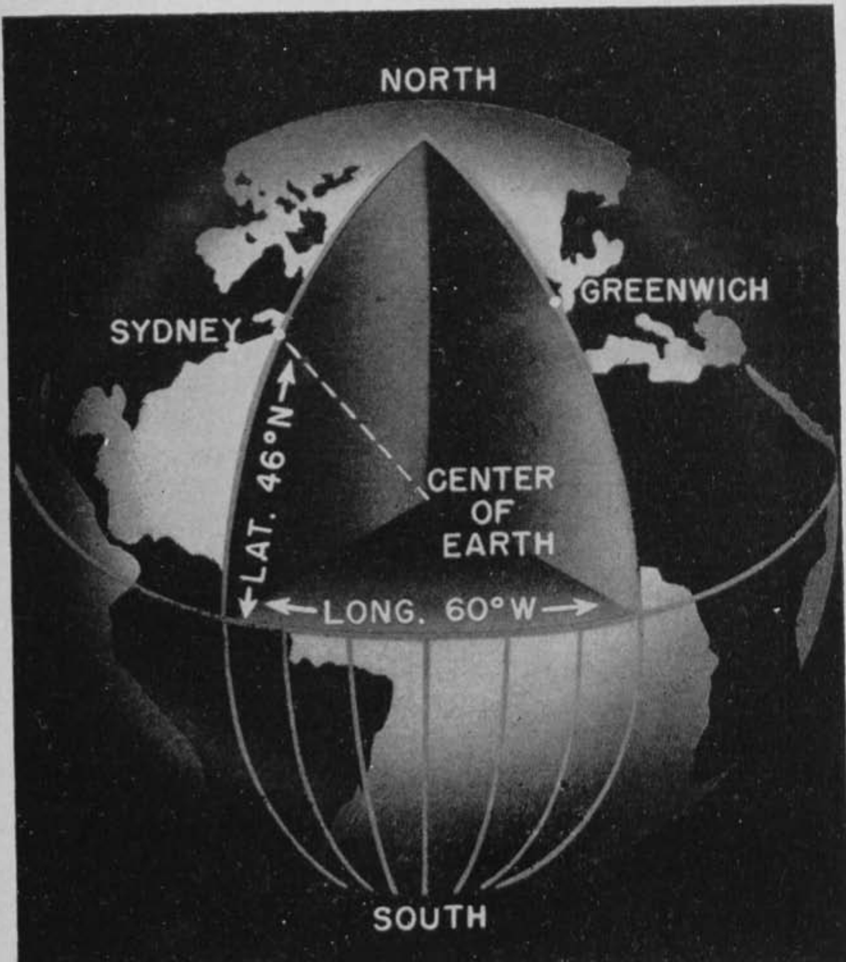



*Figure 32. Globe showing latitudes and longitudes.*

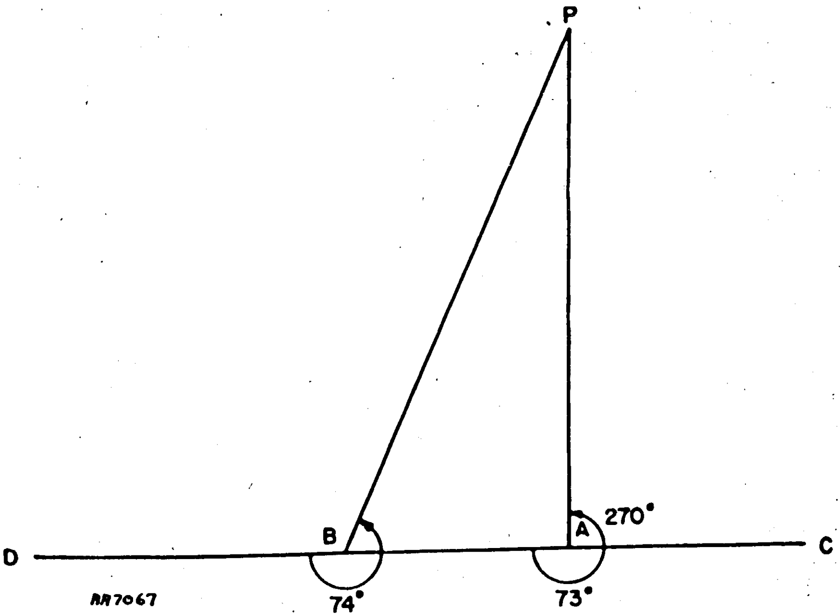



*Figure 33. Convergence of meridians.*

azimuth by 180° plus or minus the convergence of the meridians through the two points at the ends of the line. The true back azimuth and the true forward azimuth of a line differ by exactly 180° only when the line is due north of south or along the Equator.

*d.* The formula for the amount of the convergence of the meridians between any two points is:

*Convergence (in angular value) = difference in longitude of the two points (in angular value) × sine of the mean latitude of the two points.* The value of the convergence obtained by the use of this formula will be expressed in terms of degrees, minutes, or seconds, according to which unit is used to express the difference in longitude.

## Section II. MILITARY GRID SYSTEM

### 63. General

The length and direction of a line joining two points can be computed from their geographic coordinates, but the computation is long and difficult. In a system of rectangular coordinates, however, if the abscissas ($X$) and ordinates ($Y$) of two points are known, the determination

of the length and direction of the line joining them requires only the solution of a right triangle. Likewise, in such a system the position of a point may be determined if the distance of the point from two reference lines intersecting at right angles is known. The two distances which locate the point are measured parallel to the horizontal and vertical axes and are known as the "$X$" and "$Y$" coordinates, respectively. (See fig. 34.) The unit of linear measure in the American military grid system is the *yard*. All measurements in feet are changed to yards before calculation is commenced.

## 64. Military grid system

*a.* For the above reasons, a system of rectangular coordinates, known as the "Military Grid" system, has been adopted as standard for military maps of the United States. In this system, the area of the United States and part of Alaska is divided into nine north and south belts or zones. Each zone is 9° longitude in width. In the polyconic projection of each zone the central meridian of the zone is the $Y$ axis of that zone and the parallel of 40° 30′ north latitude is the $X$ axis of all zones.

*b.* With the intersection of the $X$ and $Y$ axes in each zone as an origin, a system of lines parallel to each axis is drawn, forming a network of squares on the map. The distance to each axis is drawn, forming a network of squares on the map. The distance between grid lines, in even thousands of yards, varies from 100 to 50,000 yards, depending on the scale of the map. To avoid the use of negative coordinates, the geographic origin of the grid system for each zone is given the coordinates: $X = 1{,}000{,}000$; $Y = 2{,}000{,}000$.

*c.* To avoid the confusion which would result when operating in areas

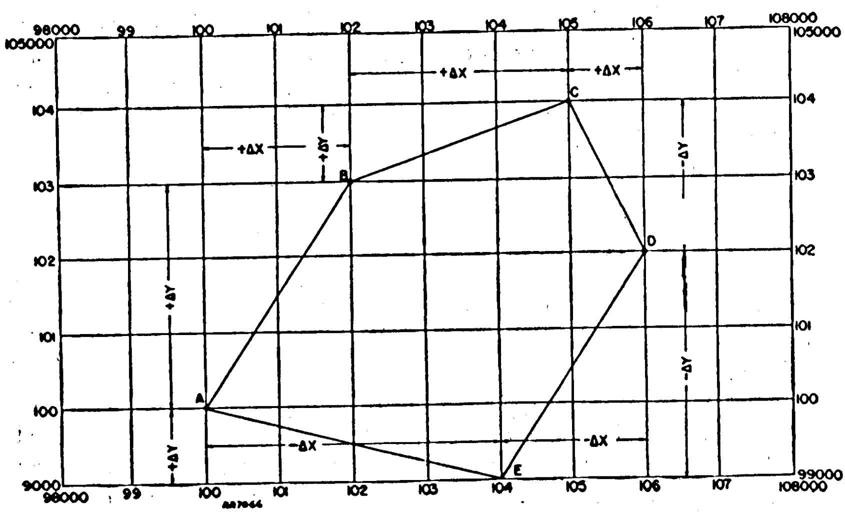



*Figure 34. Rectangular coordinates.*

lying in two adjacent zones, it was decided to have zones overlap one another by 1°. The designation of zones, their central meridians, and limiting meridians are shown in the following table:

| *Designation (zone) United States* | *Central Meridian* | *Limiting Meridians* | |
|---|---|---|---|
| *A* | 73° West | 68° 30′ | 77° 30′ |
| *B* | 81 West | 76 30 | 85 30 |
| *C* | 89 West | 84 30 | 93 30 |
| *D* | 97 West | 92 30 | 101 30 |
| *E* | 105 West | 100 30 | 109 30 |
| *F* | 113 West | 108 30 | 117 30 |
| *G* | 121 West | 116 30 | 125 30 |
| *H* | 129 West | 124 30 | 133 30 |
| *J* | 137 West | 132 30 | 141 30 |
| Foreign possessions: | | | |
| Canal Zone | 81 West | | |
| Hawaii | 158 West | | |
| Philippine Islands | 122 East | | |

The zones *A* to *G* are shown graphically in figure 35.

*d.* The military grid appears registered on gridded maps in two series of parallel lines at right angles to each other. The central meridian of the overlap between adjacent grid zones is the dividing line between the zones. Any map which falls within the 1° overlap between grid zones always shows in solid black lines the grid of the zone to which the map pertains. The grid of the adjacent overlapping zone may also appear registered by means of grid intersections (small crosses) on the face of the sheet and ticks around the border lines. The scheme is useful in effecting transition of data from one zone to another. The lines of the overlapping zone when needed may be struck in by simply joining the registration points. Since the grid lines of each zone are all parallel to the central meridian of the zone and since meridians converge to the poles, the lines of overlapping grids will always cross at distinct angles. (See fig. 36.)

*e.* The system of north and south grid lines on a gridded map is referred to as the *Y* lines and the system of east and west grid lines is referred to as the *X* lines. All *Y* lines are parallel to the central meridian of the grid zone in which the map falls. All *X* lines are at right angles to this central meridian. The base directions established by the *Y* lines are known as "grid north" and "grid south." The base directions established by the *X* lines are known as "grid east" and "grid west."

*f.* The distance of each north and south grid line, grid east of the zero point or origin of coordinates, is marked in thousands of yards normally along the south border of a gridded map. The distance of each east and west grid line, grid north of the zero point or origin, is marked in thousands of yards, normally along the west border of a gridded map.

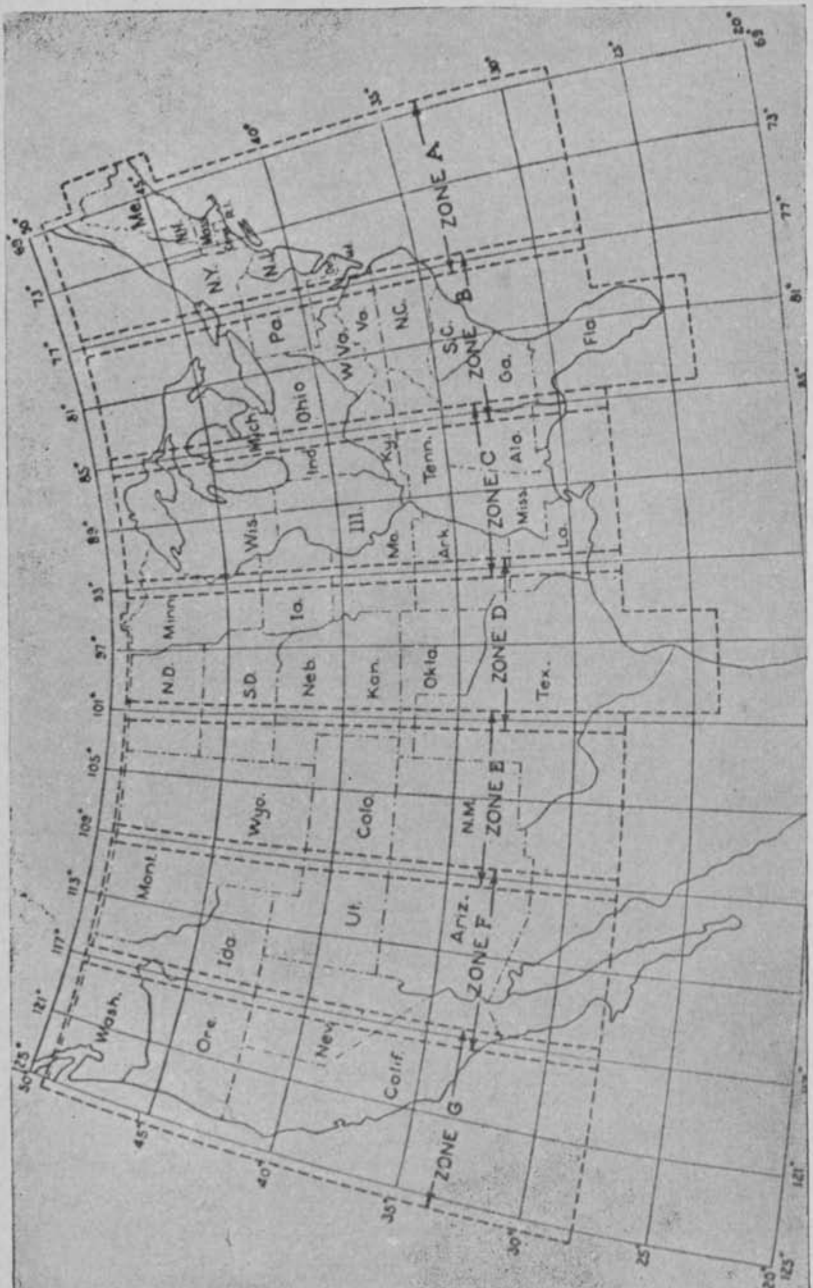



*Figure 35. United States grid zones.*

The numbers which identify the north and south grid line and the east and west grid line which intersect at or nearest to the southwest corner of a gridded map are written out in full in yards. In marking all other grid lines, the digits common to the sheet may be omitted. When the grid of an overlapping zone appears registered by ticks and grid intersection on a map, the ticks of the north, south, east, and west, grid lines, respectively, which intersect at or nearest to the southeast corner, are marked in full yards. No other grid lines of the overlapping zone are marked.

*g*. In any system of rectangular coordinates, if the abscissas $X$ and ordinates $Y$ of two points are known, the determination of the length and direction of the line joining them requires only the solution of a right triangle. Likewise, in such a system the position of a point may be determined if the distance of the point from two reference lines intersecting at right angles is known. The two distances which locate the point are measured parallel to the horizontal and vertical axes and are known as the "$X$" and "$Y$" coordinates, respectively.

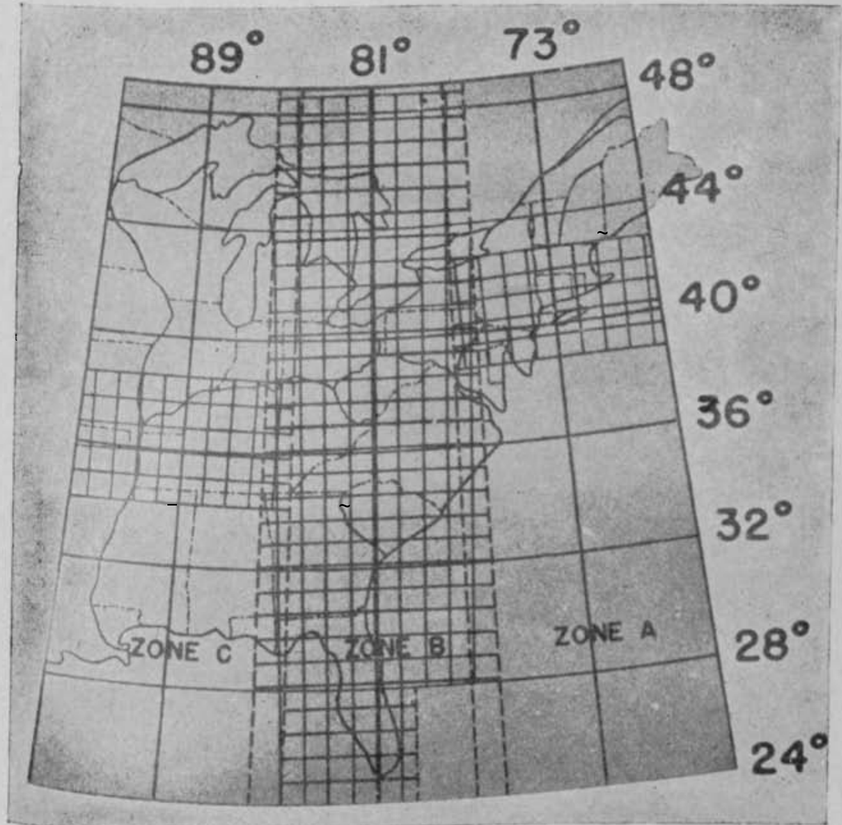



*Figure 36. Overlapping zones.*

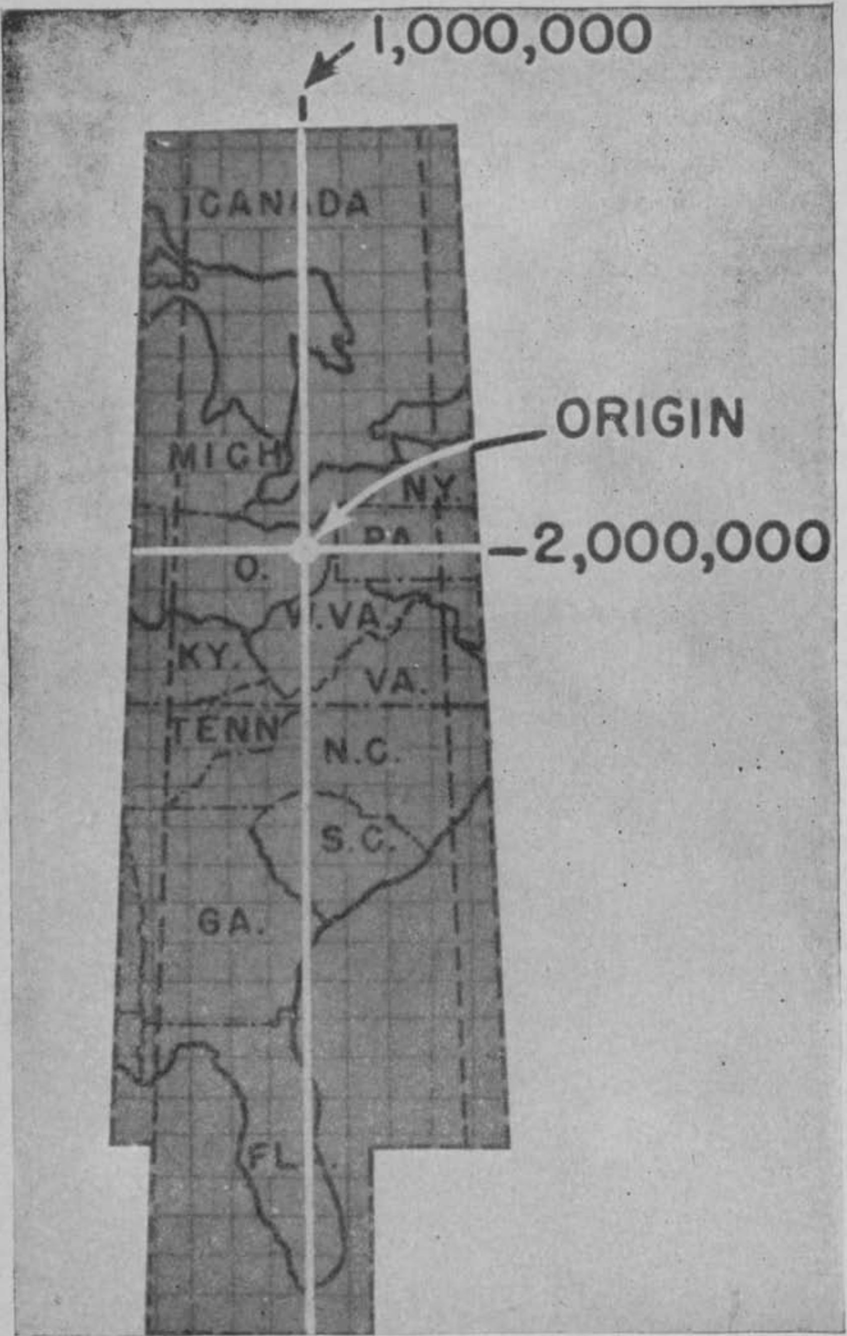



*Figure 37. Origin of zone B.*

*h.* A complete explanation of the Military Grid System with tables giving grid coordinates of the intersection of every 5′ of latitude and every 5′ of longitude within the United States and with formulas for the conversion of geographic coordinates into grid coordinates and vice versa, may be found in Special Publication No. 59, Grid System for Progressive Maps in the United States, United States Coast and Geodetic Survey. Tables for converting geographic into grid coordinates in the vicinity of the Canal Zone have been prepared by the Corps of Engineers. However, no tables are available for this conversion in Hawaii or the Philippine Islands and it is therefore necessary to compute the grid coordinates for given positions. Special Publications Nos. 5 and 8, United States Coast and Geodetic Survey, or TM 5–235, provide the necessary data for this computation.

*i.* In this manual the term "military grid coordinates" refers to those coordinates computed or scaled from the zone polyconic type of projection.

## 65. Determinaton of grid coordinates

There are several methods of obtaining the military grid coordinates of a point:

*a.* The conversion of the geographic coordinates (latitude and longitude) to military grid by interpolation in Special Publication No. 59, United States Coast and Geodetic Survey, subject: "Grid System for

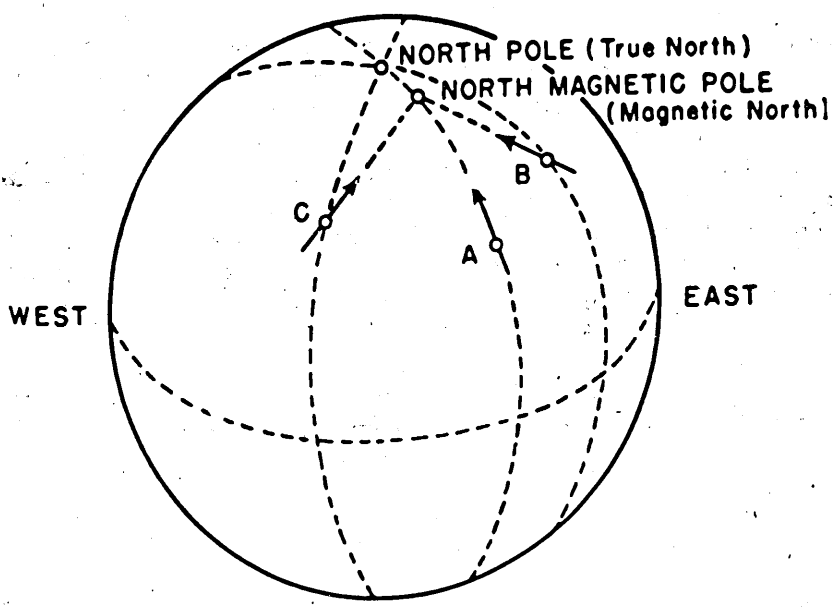



*Figure 38. Geographic position of Magnetic Pole.*

Progressive Maps in the United States." The tables in this text show the grid coordinates in yards of the intersection of each fifth minute of longitude with each fifth minute of latitude within the whole area covered by the grid system in the United States.

~~*b.* The conversion of geographic coordinates to military grid coordinates by *formula* as explained in paragraph 117*f*, TM 5-235.~~

*c.* The scaling of the coordinates from a grid map.

*d.* The running and the computation of a traverse, using several known points as a basis to determine the coordinates of an unknown point (ch. 6).

*e.* The determination of position of an unknown point by intersection (ch. 7).

*f.* The determination of position of an unknown point by resection (ch. 8).

## Section III. AZIMUTH

### 66. General

Azimuth is the most convenient and commonly used method of expressing direction. For most military purposes, azimuth is the horizontal angle measured in a clockwise direction, from the north point of a north-south line through the point of measurement, to the point to which the angle is measured. In the Southern Hemisphere it is sometimes simpler to reckon azimuth as being measured from the South point rather than the North. There are three main methods of determining direction namely by compass, by celestial observation, and by map. A direction determined by compass is a direction referred to *magnetic north* and an azimuth determined by compass is known as *magnetic azimuth.* A direction determined by celestial observation is a direction referred to *true north* and an azimuth determined by celestial observation is known as *true azimuth.* A direction determined by an oriented map with the grid lines shown is referred to *grid north* and an azimuth determined by an oriented map using grid lines is known as *grid azimuth.*

### 67. Relation between azimuths

*a.* Grid north, magnetic north, and true north are rarely the same direction. Magnetic north is determined by the position of the magnetic pole on the earth. This magnetic pole does not coincide with the north pole of the earth (see fig. 38) and so magnetic north varies from true

north according to the observer's position on the earth. Similarly, the south magnetic pole is not at the South Pole of the earth.

*b*. The north point determined by celestial observation is always true north irrespective of the observer's position on the earth.

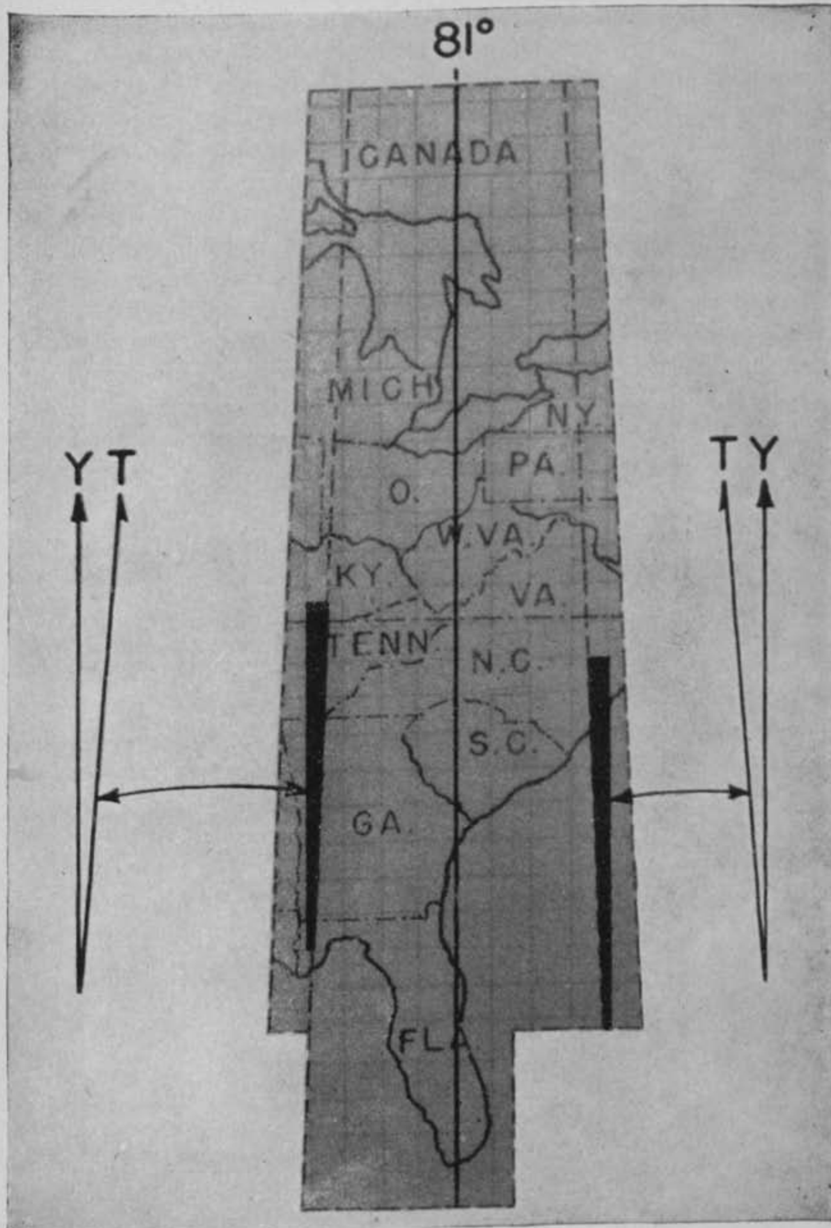



*Figure 39. Divergence of true direction from grid direction.*

*c.* Grid north is established on a map by drawing the north-south grid lines parallel to the central meridian of the map. The grid line coinciding with the central meridian of the map will then be lying in a true north-south direction and grid north and true north will be the same direction along this line. However, along the edges of the map the north-south grid lines will be parallel to the central grid lines but true north will be parallel to a meridian at that point and so will differ from grid north for that point. This divergence results in a difference between the grid azimuth and true azimuth of any line except a north and south line on the central meridian. Referring to figure 39, it is readily apparent that at all points east of the central meridian, grid north is east of true north and the grid azimuth is *less* than the true azimuth, while at all points west of the central meridian, grid north is west of true north and the grid azimuth is *greater* than the true azimuth. The difference between the true azimuth and the grid azimuth of a point at the apex of the triangles is the angle between $Y$ and $T$ in each case.

*d.* The general formula for the difference between true azimuth and grid azimuth is: *Divergence or declination (in angular value) equals difference in longitude between the central meridian of the zone and the point for which the divergence is desired (in angular value) times sine*

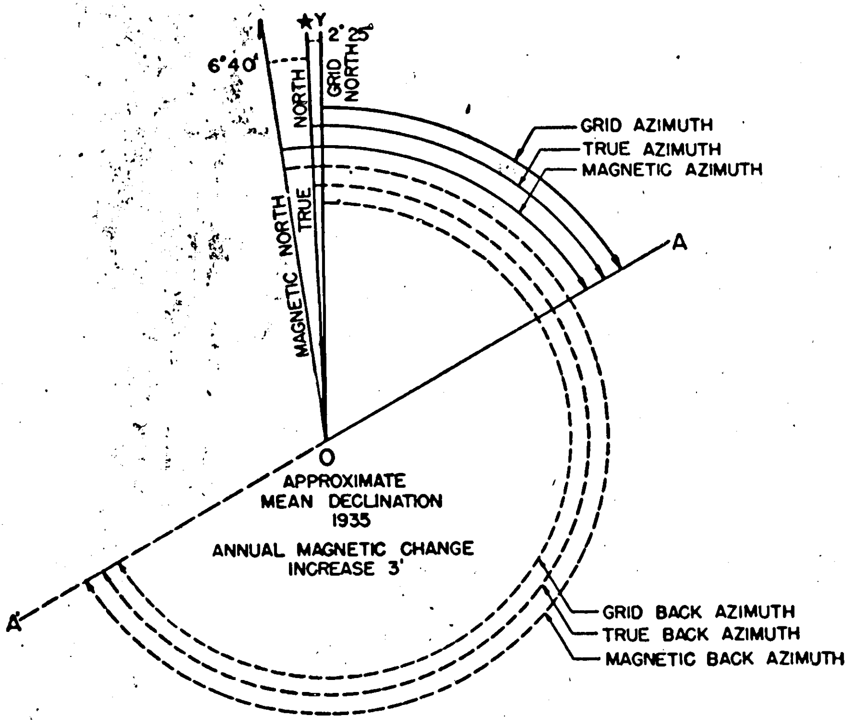



*Figure 40. Relationship between three base directions on a map, showing corresponding azimuths and back azimuths of line OA.*

*of the latitude of this point.* The value of the divergence obtained by the use of this formula is expressed in degrees, minutes, or seconds, according to which unit is used to express the difference in longitude. It must be remembered that this formula is accurate to within a few seconds only (depending on the difference in longitude between the central meridian and the observer's station) and that if a more precise value is desired, table L, TM 5–236 (corrections for the reduction of geographic azimuths to grid azimuths), is used. However, since for most practical artillery purposes it is sufficiently accurate to determine azimuths to the nearest half minute, the formula is sufficiently accurate and saves making a difficult interpolation of table L, TM 5–236.

*e.* The back azimuth of a line is the azimuth of the line extended in the opposite direction. It is the azimuth plus or minus 180°. Thus in figure 40, the azimuth of the line from *O* to *A* (or *OA*) differs from the azimuth of the line from *O* to *A′* (or *OA′*) by 180° and the azimuth of the line *OA′* is equal to the back azimuth of the line *OA*.

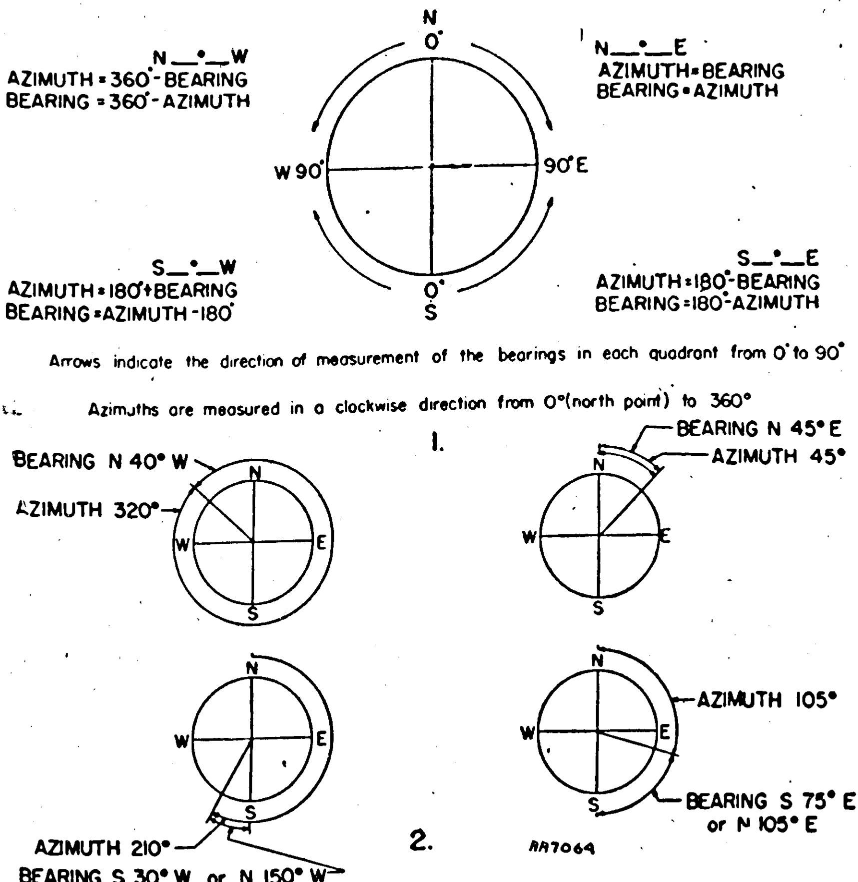



*Figure 41. Relationship between azimuths and bearings.*

## 68. Declination

Declination is the difference in direction between true north and either magnetic north or grid north. Hence, there are two declinations, magnetic declination and grid declination.

*a.* MAGNETIC DECLINATION. Magnetic declination is the difference in direction between true north and magnetic north. In some localities, the compass needle points east of true north; in these localities the magnetic declination is east. For instance, the compass needle in a certain area points 10° east of true north; the magnetic declination in that area is, then, 10° east. In some localities the compass needle points west of true north; in these localities the magnetic declination is west. Since the magnetic pole is not fixed, but is subject to cycles of changes of position due to obscure causes, the magnetic declination in any one locality is subject to change, the amount of which can be predicted from the records of past variations. On the margin of standard military maps is shown, in a diagrammatic form, the average magnetic declination for the locality illustrated by the map at a stated date; also its annual change and whether increasing or decreasing.

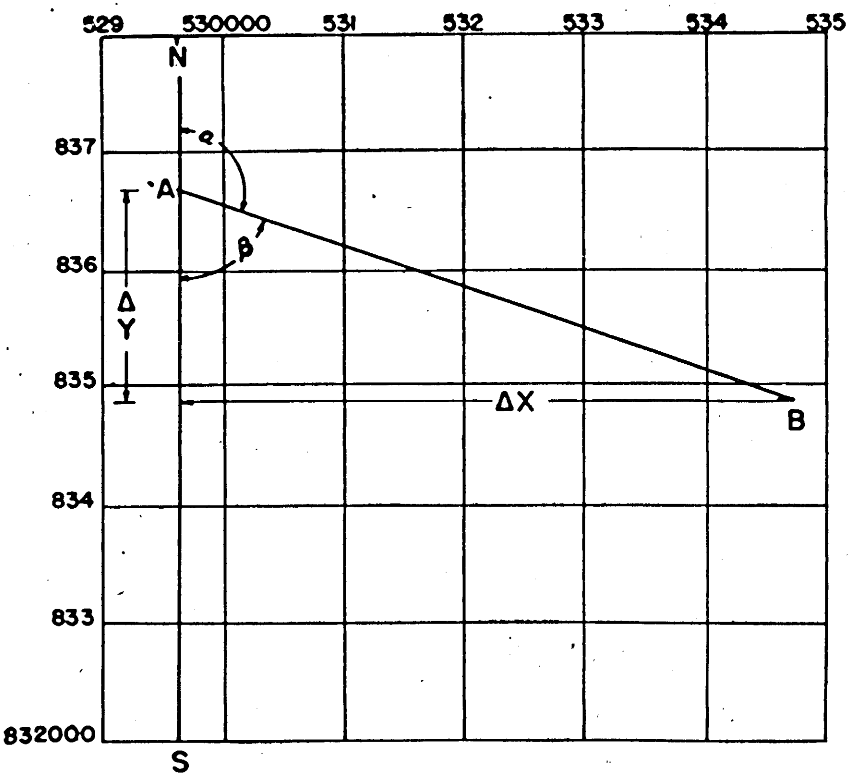



*Figure 42.*

*b*. Grid declination. Grid declination is the difference in direction between true north and grid north. (See fig. 40.)

## 69. Bearing

Bearings are used to express directions as determined by a compass or celestial observation. The bearing of a given line is the angle and direction which the line makes with respect to the north or south base direction line. The direction is indicated by giving the angle from the north or south toward a basic direction either east or west, such as north 60° east. However, the angle may be greater than 90° in which case the angle is expressed in the same way but the east or west direction is an expression of direction of rotation. In using formulas for solution of celestial observations, it is possible for the solution to be indicated as an angle over 90° measured from the elevated pole (North Pole in the Northern Hemisphere, South Pole in the Southern Hemisphere) in an easterly or westerly direction, such as north 120° east. This means that the angle was measured from the north, 120° toward the east. However, 120° causes the angle to pass the east point and progress 30° beyond, and toward the south. In this case the term "east" is merely a direction of initial rotation. Figure 41 illustrates bearings and azimuths and the relationship between the two. Bearings are not as convenient as azimuths for military purposes and so a bearing is usually converted to azimuth to simplify recording, transmission and plotting.

## 70. Computation of grid azimuth and distance

*a*. Bearings. The direction or azimuth of a line is measured in a

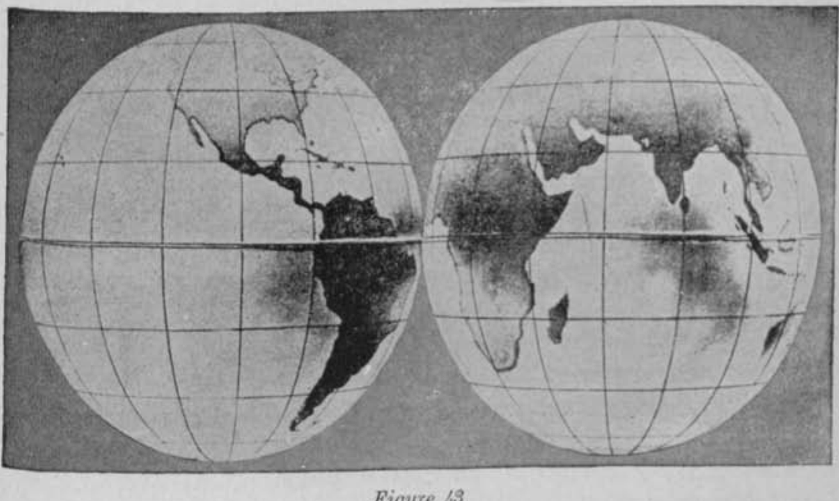


*Figure 43.*

The earth is difficult to represent on a map because it is a sphere, and a map is a flat plane.

clockwise direction from the north or south point, but in the Northern Hemisphere is usually measured from the north. In this manual, azimuth will be considered to be measured from north except when specifically stated otherwise. Azimuth may be expressed in degrees clockwise from 0° to 360°, or in mils from 0 to 6400. In figure 42, the angle $\alpha$ represents the azimuth of the line *AB*. The bearing of a line is the horizontal angle which it makes with a north and south line; when making computations, the bearing is usually expressed in a value less than 90° and, therefore, it is sometimes measured from the north and sometimes from the south, clockwise or counterclockwise. In figure 42, the angle $\beta$ represents the bearing of the line *AB*. The bearing of a line is always the angle whose tangent is $\Delta X/\Delta Y$.

It is good practice, in determining the azimuth of a line whose coordinates are given, to draw a rough diagram similar to the one in figure 42, and to note by inspection the quadrant in which the line being calculated lies and the approximate azimuth of the line. In converting bearings to azimuths, it should be remembered that bearings in the first and fourth quadrants are measured from north, and bearings in the second and third quadrants are measured from south.

*b.* $\Delta y$ CORRECTIONS. The azimuth and distance computed from the coordinates of the United States military grid system will not be exact due to the fact that $\Delta y$ contains the error of the polyconic projection commonly known as the magnification of scale error. ~~The error of the polyconic projection is a result of projecting a curved surface onto a plane.~~ The correction for magnification of scale is dependent upon the distance of a measured line from the central meridian of a grid zone. An accurate value of $\Delta y$, as it would be measured on the ground, is obtained by applying a correction taken from table XLIX, TM 5–236. This correction is based on the fact that the military grid distance, in a north and south direction, *is always greater than the ground distance.* In other words, when it is desired to convert distances computed from military grid coordinates into true distances on the ground, $\Delta y$ is first corrected for magnification of scale by *subtracting* the value given in table XLIX, TM 5–236. If, on the other hand, it is desired to determine the map coordinates of a point, $\Delta y$ as actually measured on the ground is corrected for magnification of scale by *adding* the value given in table XLIX, TM 5–236. In correcting $\Delta y$ at points in the 1° overlap between zones, care must be taken to obtain the correction for the proper zone for the map which is being used.

*c.* CALCULATION. Given the military grid coordinates of two points, *A* and *B*, as shown in figure 42. Compute the azimuth and distance from *A* to *B*. (Latitude 30° 50′ N; Longitude 77° 30′ W; Zone A) Coordinates:

NOTE: $\Delta$ is used as the symbol for difference.

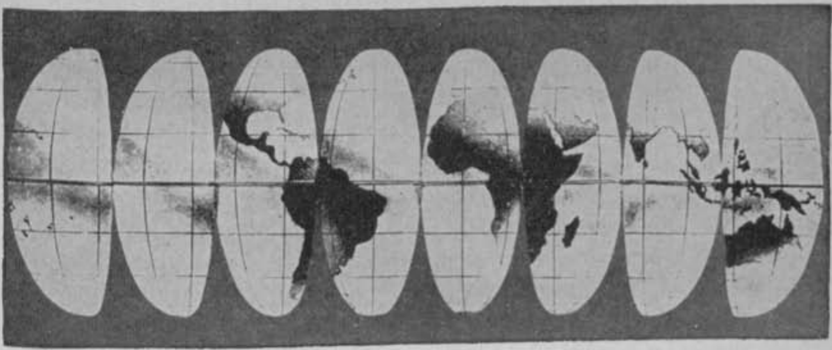


*Figure 44.*

The sphere would appear as shown if divided into eight equal sections.

| | $X$ | $Y$ |
|---|---|---|
| $A$ | 529,593.1 | 836,685.3 |
| $B$ | 534,784.7 | 834,807.0 |

$\Delta x = -5{,}191.6$ yards $\qquad \Delta y = 1{,}878.3$ yards

$\Delta$y correction (table XLIX, TM 5–236) $= -4.3$ yards

Corrected $\Delta y = 1{,}874.0$ yards

$$\text{Tangent bearing } (\beta) = \frac{\Delta x}{\Delta y}$$

$$\begin{aligned}
\text{Log } 5191.6\ (\Delta x) &= 3.71530 \\
\text{Log } 1874.0\ (\Delta y) &= 3.27277 \text{ (subtract)} \\
\text{Log tan bearing } (\beta) &= 0.44253 \\
\text{Bearing } (\beta) &= 70^\circ\ 09'\ 08'' \text{ (E of S) quadrant II} \\
\text{Subtract from } & \phantom{=}\ 180^\circ\ 00'\ 00'' \\
\text{Azimuth } AB &= 109^\circ\ 50'\ 52'' \\
AB &= \Delta x / \sin \beta \\
\text{Log } 5191.6\ (\Delta x) &= 3.71530 \\
\text{Log sin } 70^\circ\ 09'\ 18''\ (\beta) &= 9.97341 \text{ (subtract)} \\
\text{Log } AB &= 3.74189 \\
AB &= 5{,}519.4 \text{ yards}
\end{aligned}$$

NOTE: $AB$ may also be obtained by the use of $\Delta y$ in the equation, $AB = \Delta y / \cos \beta$.

*d.* COMPUTATION OF DISTANCE. For precise work, all distances must be corrected for magnification of scale. As noted above, the error in the north-south direction is appreciable as soon as one works away from the central meridian of the zone. This error may be calculated by trigonometry in per cent (or yards error per 100 yards) by determining the convergence of meridians by the formula in paragraph 62*d*, or it can be found by double interpolation from table XLIX, TM 5–236, in terms

of yards error per 1,000 yards. The distortion appears in the north-south vector of any line when we are working with military grid coordinates. The distortion decreases with increasing latitude, but increases with longitudinal difference between the point under discussion and the central meridian of the zone. It actually ranges from zero at all points on the central meridian to 2.754 yards per 1,000 yards in the north-south direction at 24° north latitude, and at the edge of the zone or 4° 30′ from the central meridian. One thousand yards on the ground in a north-south direction when placed on the map (or when obtaining the military grid coordinates of the point) must be stretched by this distortion or by the magnification of scale correction, to make it fit the map. Likewise, in taking coordinates from the map, to obtain ground distances, or azimuth, the $\Delta y$, or the north-south vector of the line must be shrunk by the same correction. For example, 1,000 yards in a north-south direction on the ground at latitude 24° north, and longitude 76° 30′ west, would actually have to be stretched until it was $1{,}000 + 2.754 = 1{,}002.754$ on the map. Similarly, if we took the distance from the map in order to obtain the ground distance, the map distance of 1,002.754

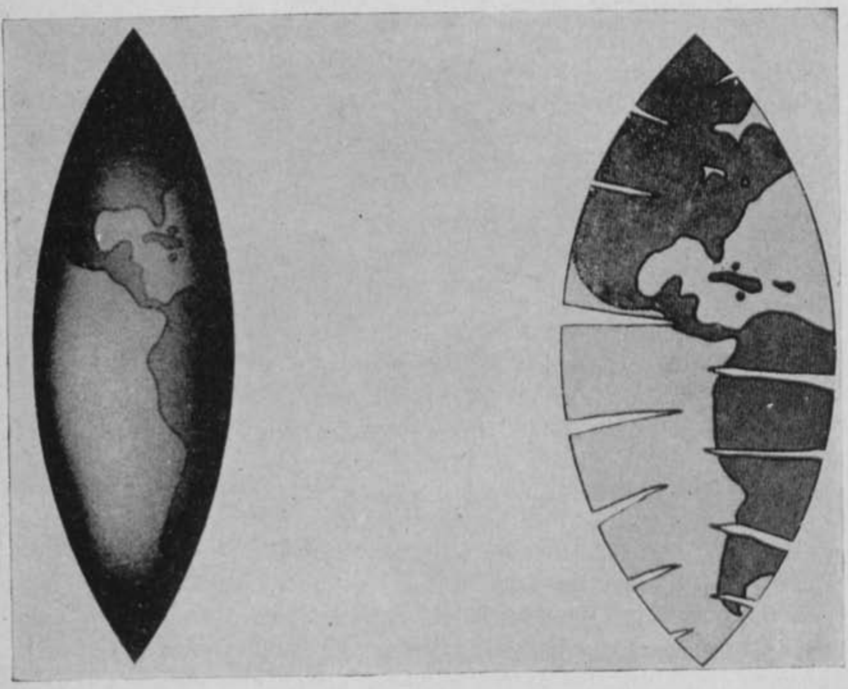


*Figure 45.*

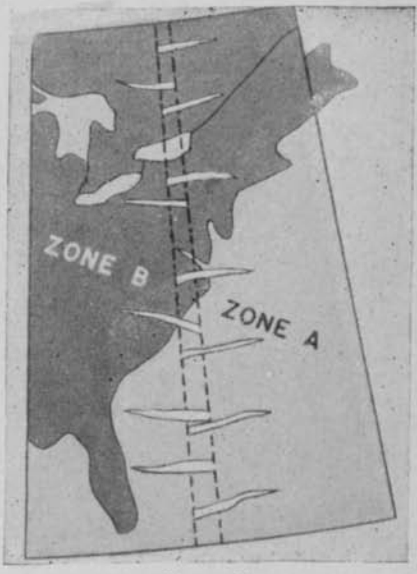
If the section shown on the left is flattened to appear as a map on a flat plane, the north-south lines at the edge of the section will crack and become distorted as shown on the right.

yards would have to be shrunk by 2.754 yards, in order to obtain the proper ground distance of 1,000 yards.

*e.* USAGE. The use of magnification of scale corrections should be understood by survey personnel so that in work of precise nature the

When the grid system is placed on the map of a military grid zone, the north-south grid distances will be greater than the true distances on the ground.

*Figure 46.*




The east and west sides of each zone have these distortions which are called magnification of scale errors.

*Figure 47.*

THE WORLD POLYCONIC GRID

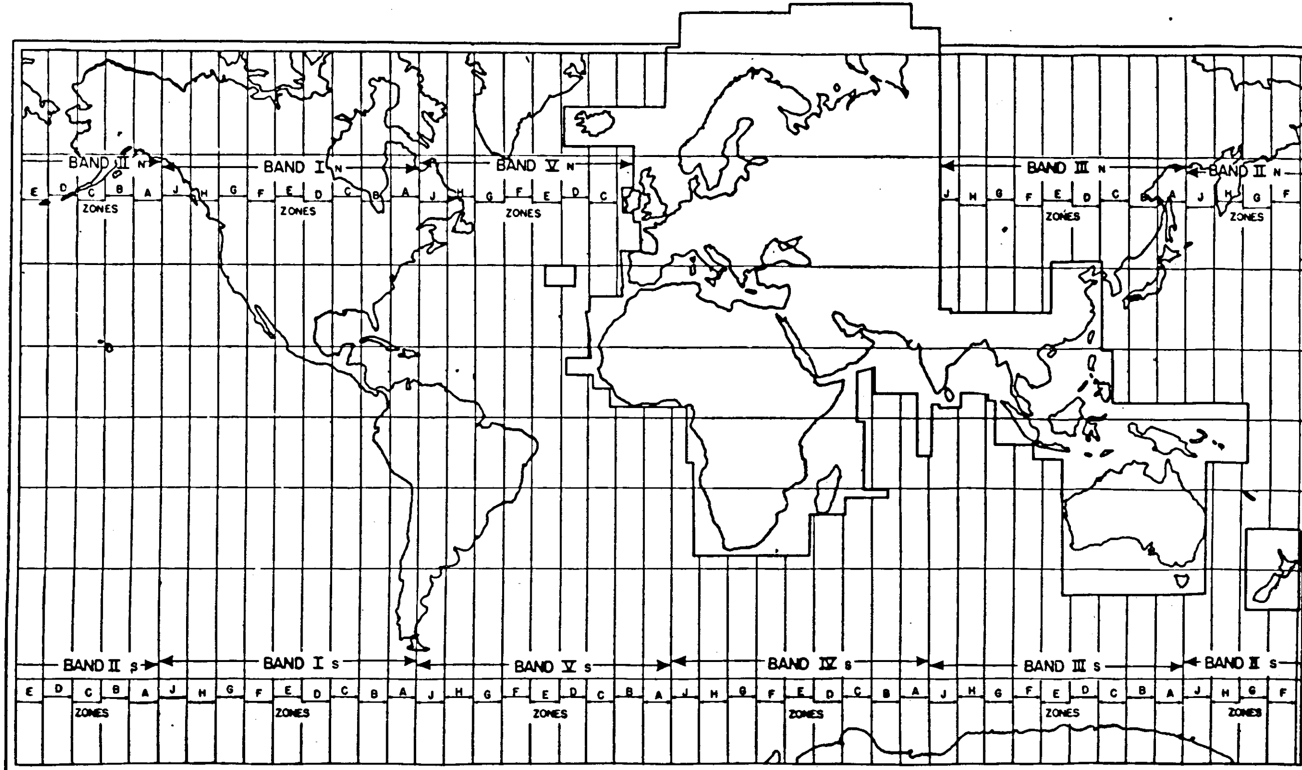



*Figure 48. World Polyconic Grid.*

proper corrections can be made. However, when a rapid survey is being made or when the area of the survey is near the center of the zone, the corrections may be smaller than the expected errors in the survey, in which case the corrections for magnification of scale are superfluous. It is advisable to estimate mentally the percentage of error that might be expected considering the method used in measuring distances and angles. For example, the average error for a base line measured with a steel tape using plumb bobs and ordinary care is about 1′ in 5,000′ or 0.2 yards in 1,000 yards; therefore, if the magnification of scale correction is less than 0.2 yards in 1,000 yards, it might as well be ignored. However, if very precise measurement is being made, it should be included. In a highly mobile situation, the inaccuracy of measurement due to rapid work will usually preclude the necessity of making a correction for magnification of scale.

## 71. The World Polyconic Grid

The World Polyconic Grid is an extension of the U. S. Military Grid

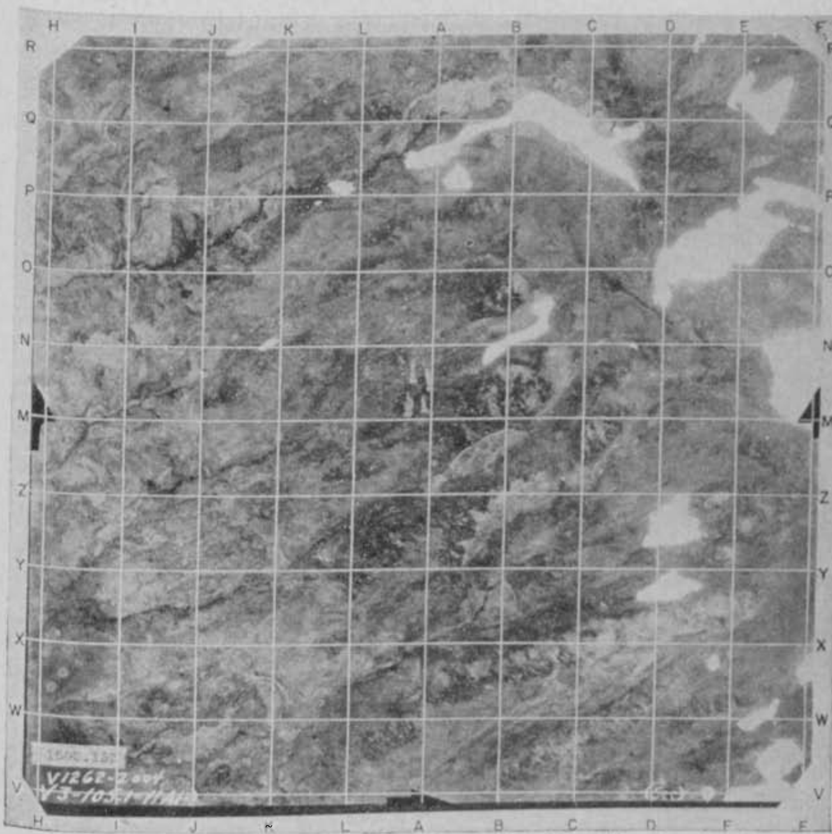



*Figure 49. Wide-angle photo with point-designation grid printed on it. (Note collimation ticks.)*

System to cover those parts of the world not gridded by the British and areas not previously gridded by the United States. The world is divided in an east and west direction into five north-south divisions called "Bands." Each band is made up of nine zones in the same way as is the U. S. Military Grid System. The nine zones *A* to *J* in the U. S. Military Grid System are included in and comprise the total width of Band I. Band I, however, takes in all the area between Latitude 72° north and 70° south and takes in the same width as Zones *A* to *J*, that is, longitude 68° 30′ west to 141° 30′ west. Each band is divided at the equator and designated as Band *I-N* for the north half and Band *I-S* for the south half. Band II is the next band west of Band *I* and takes in the area from Longitude 140° 30′ West to 146° 30′ East. Bands III, IV, and V are the next succeeding bands in a westerly direction. However, where a foreign grid system has been established such as in the European and African area the grid system of that area is used instead of the World Polyconic Grid. Each band is divided into nine standard size zones lettered from *A* to *J* in the same way as Band I. Figure 48 shows an outline of the bands throughout the world. The portions that are shown blank are sections of the world covered by some other type of grid and for which gridded maps are available. The Corps of Engineers have prepared a publication entitled "Grid System for Military Maps for 49° to 72° north latitude," which gives the grid coordinates for 5-minute intersections to amplify the data contained in Special Publication No. 59, United States Coast and Geodetic Survey, "Grid System for Progressive Maps in the United States."

## Section IV. LOCAL PLANE COORDINATES

### 72. Local plane coordinates

In certain localities or instances, standard grid system maps or data may not be available. In such cases, it is necessary to establish a system of *local plane* coordinates. Local plane coordinates are a system of coordinates similar to the military grid coordinates except that the point of origin of the system is some local point rather than a specified zone point. This local point is ordinarily given grid coordinates such as $X = 100{,}000$ and $Y = 200{,}000$. A true north-south line is determined through this point and a grid system with resulting rectangular axes is superimposed on the map. Inasmuch as the local plane coordinate system is usually used for a relatively small area, no corrections are necessary for magnification of scale. This system may logically

be expected to be used when units are beginning operations in a new territory where maps or a standard grid system are not available. The local plane coordinate system may be expanded from the initial system as the situation demands.

## Section V. POINT DESIGNATION GRID

### 73. Point designation grid

*a.* Aerial photographs are used initially in territory that is unmapped or for which maps are unavailable. The printing of accurate fire-control grids on photomaps usually is impracticable because of distortion and the difficulty of reproducing a photo to a desired scale. Therefore, an arbitrary grid, known as the point-designation grid, is sometimes used. This grid has no relation to the actual scale or orientation of the photo; it serves only for point or target designation and normally is not suitable for measurement of distance or azimuth. For convenience, the dimen-

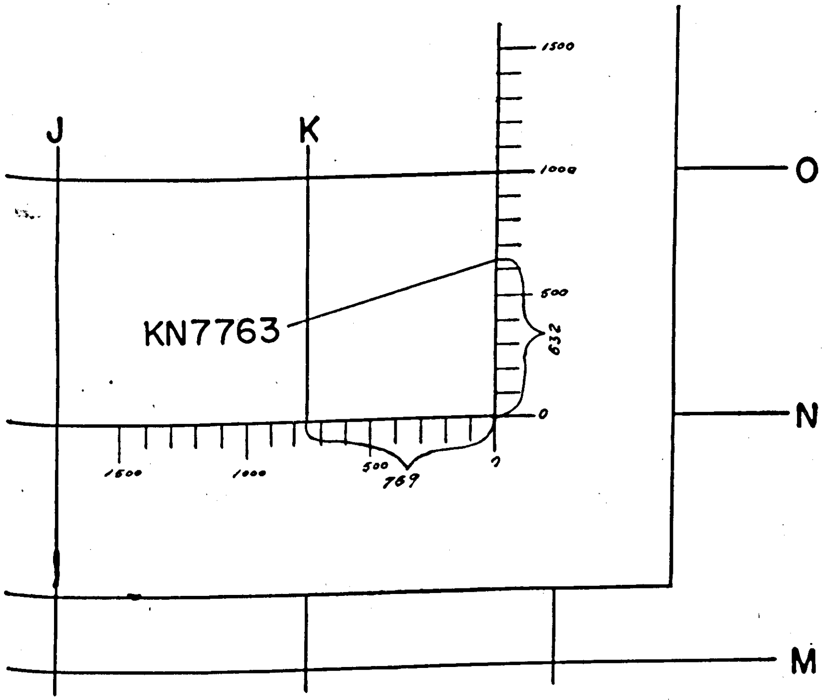



*Figure 50. Reading coordinates on a point-designation grid.*

sion of the grid square is ~~1.8~~ 1.44 inches; the 1:25,000 scale may then be used for determining and plotting the coordinates of points.

~~b. The point designation grid~~ may be printed on the photo (as is the case with the wide-angle photo, fig. 49) or, for photos without the grid, a transparent template with the grid printed on it may be used. It is essential that all concerned place their templates on the photo in exactly the same manner; standard markings on the photo permit such identical placing. Many photos have collimation ticks in the center of each side of the photo from which the center may be found. The grid is designed to have its two central lines, the *AA* line and the *MM* line, pass through the center of the photo.

*c.* To determine the coordinates of a point (fig. 50) the intersecting grid lines to the left and below the grid square in which the point is located are first indicated by two letters; then the two numerical coordinates are read to the right and up, in that order, just as for the fire-control grid. For example, using a 1:25,000 scale to the nearest ten yards, the coordinates of the point in figure 50 are KN7763. If less accuracy is sufficient, the coordinates are KN86.

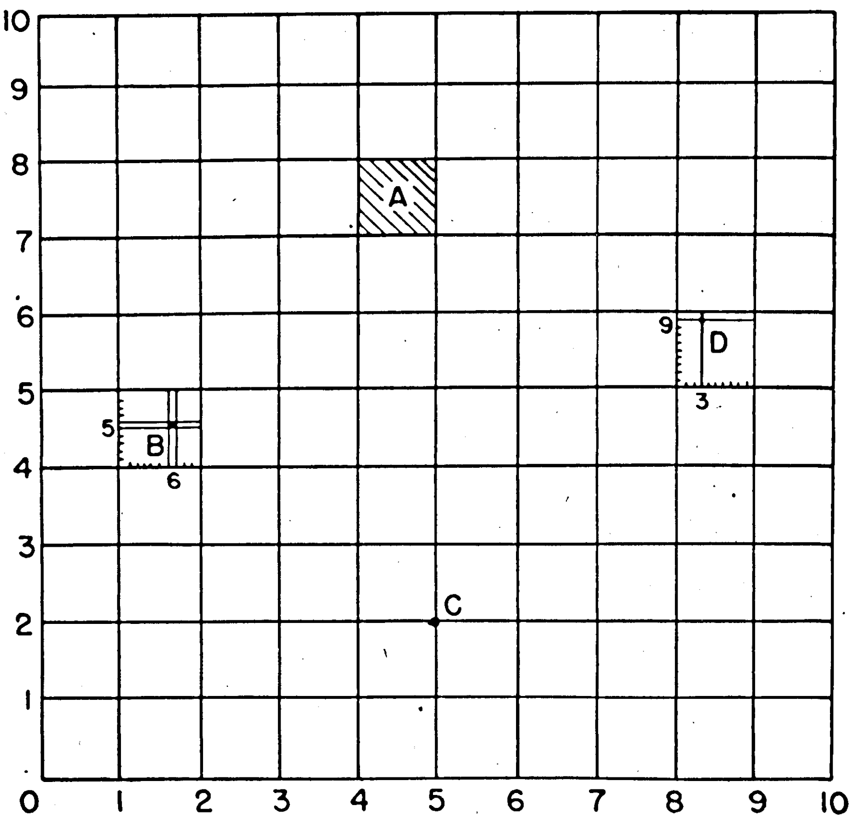



*Figure 51. Diagram of basic grid (M).*

## 74. Jan grid

*a.* A standard grid, known as the JAN (Joint Army-Navy) grid, is employed by the Army when operating jointly with the Navy and at such other times as necessary. The JAN grid permits the prompt and accurate transmission between the Army and Navy of information involving the location of points and areas. The grid may readily be established or changed for the purpose of security by a brief message. It is adaptable to any scale or projection and may be used without cartographic calculation, printing, or lithographic preparation.

*b.* When not operating with the Navy, the JAN grid is well suited for use by the Army in designating coordinates on maps or charts showing only latitudes and longitudes. A rectangular grid is, in general, printed

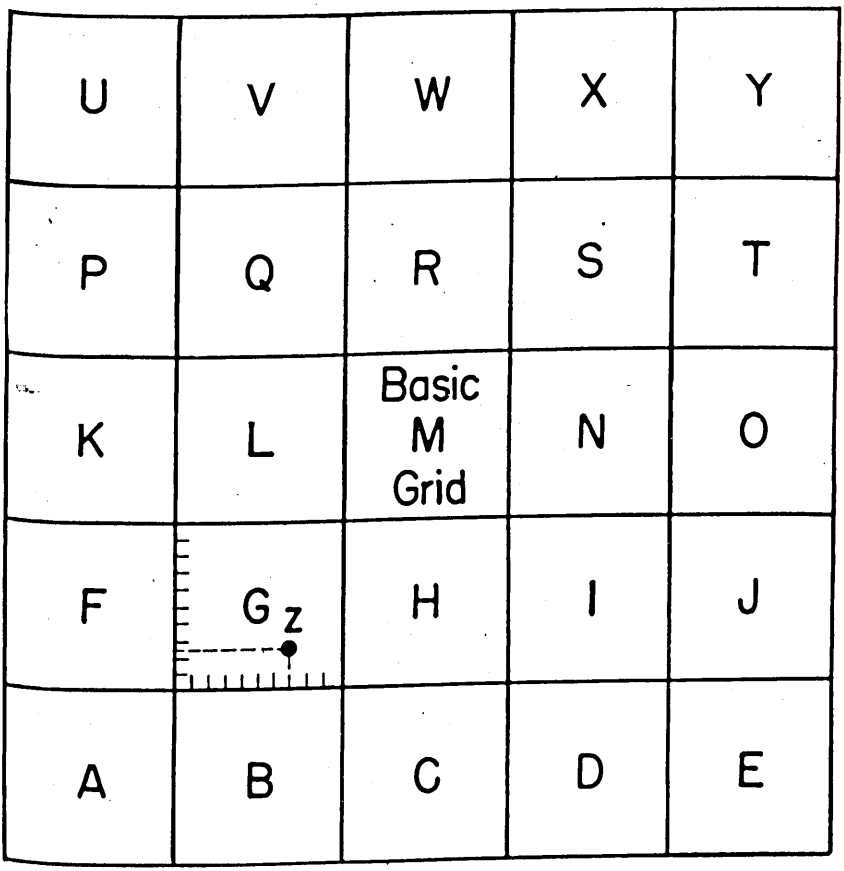



*Figure 52. Grid extension.*

on tactical maps or military maps of large scale. Maps at the scale of 1:500,000 or smaller, as well as aeronautical and hydrographic charts, generally show only latitudes and longitudes. Such maps or charts are frequently used in large scale operations for strategic, logistic, and supply purposes. Reference to position by latitude and longitude is cumbersome and does not provide the security afforded by the use of an arbitrary grid which may be readily changed.

*c.* The basic grid in this system is bounded by meridians and parallels of a designated length which are subdivided into ten equal lengths by intermediate meridians and parallels forming one hundred grid areas. (See fig. 51.) The origin of coordinates is always at the southwest corner. The base lines extend for the same prescribed number of minutes of latitude or longitude or of nautical miles (1 minute of *latitude* is 1 nautical mile). In the latter case, chart or map scales are used to measure base lengths.

*d.* The JAN grid is established in an area by designating the coordinates of the origin (or base point), which generally must be expressed in longitude and latitude, and by prescribing the length of the base lines. Assuming a point or origin at 24° west longitude and 30° north latitude and side lengths of 100 minutes of longitude and latitude, the basic grid may be established by the message: "Establish JAN grid origin 24W3ON sides 100 minutes." The basic grid is changed by selecting new origin and base lines.

*e.* Coordinates of points are given in the conventional manner without separation. In figure 51, the coordinates of point *"C"* are 52 and would be expressed in a message as "JAN point 52." Similarly, point *"D"* would be expressed as "JAN point 8359." To refer to an area within a grid, the word "area" precedes the coordinates of the southwest corner of the area. The size of the area is denoted by the number of significant figures employed. The area 47 would be the area *"A"* bounded by one-tenth of the base line lengths. The area 1645 would be the area *"B"* bounded by one-hundredth of the base line lengths. The foregoing areas would be expressed as "JAN area 47" and "JAN area 1645," respectively.

*f.* When it becomes necessary to extend the grid to cover adjacent areas, the standard grid extension shown in figure 52 is employed. It will be noted that the basic grid as initially established becomes the central grid *"M"* of an alphabetical system of equivalent grids (grid square *M* is the square shown in fig. 51 reduced in scale). While the grid extension is constructed on the basic grid *"M,"* the origin of coordinates for points or areas in any lettered grid of the system is always the southwest corner of that grid. Grids are identified within the system by prefixing the appropriate grid letter to the coordinates. For example, point *"Z"* in grid *"G"* (fig. 52) is designated "JAN point G7025."

## 75. General

The thrust line for encoding maps has proved very successful, and has unlimited possibilities. By prearrangement, all units using the thrust line must know the starting point, a secondary point, the two directions from the thrust, and the unit of measure. The thrust line used for designating locations of friendly units should be distinct from that used in designating locations of hostile elements.

## 76. Example

*a.* A line is located from RJ 109 (see fig. 53) through grid intersection 1015–1832. RJ 109 is the starting point and all locations are read outward from this point. The thrust line need not stop at the grid intersection but can be extended for any distance necessary. All locations to the right of the line are in *"M"* direction and all locations to the left are in *"Q"* direction. Other letters for these directions may be used. The unit of measure usually is in miles. This unit of measure can be anything the commander desires, but with maps having a graphic scale on them, the units of measure are usually used. Maps having only a representative fraction or aerial photographs generally use 1 inch for the unit of measure.

*b.* To locate positions by this thrust line a perpendicular must first be dropped from the desired location to the line, then the distance from the starting point to this intersection measured, giving the direction of the position, and then the distance in that direction using the same unit of measure as used along the thrust line. For example: To locate point *"A."*

*c.* We find that point *"A"* is five and four-tenths units down the thrust line, and in *"M"* direction two and five-tenths units. This is transmitted as 54M25. One decimal point is assumed at all times and need not be transmitted.

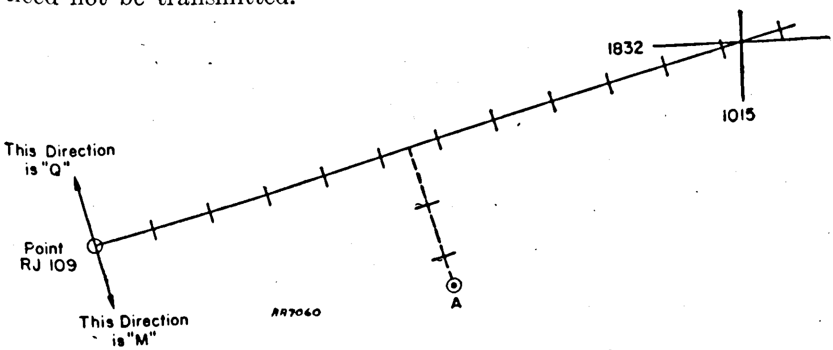



*Figure 53. Example of thrust line method.*

## 77. Map templates

*a.* A map template is a transparent plastic sheet printed and perforated as shown in the accompanying drawing. This template is used for designating specific locations on a map or photomap. Map templates are of two types, M1 and M2, exactly alike with one exception; template M1 has printed upon it *XX* and *YY* axes, while M2 does not. They are employed similarly. (See fig. 54.)

*b.* In order to use a map template, certain instructions must be given in the unit SOI (Signal Operating Instructions) in order that all individuals in the unit using the template will operate upon a common basis. These items must be changed frequently, since they provide security in transmitting data by radio in the clear. The items are:

(1) A letter code designating maps used.

(2) A figure code designating reference points on the maps.

(3) A figure system designating a numbering system for the template reference holes.

(4) Designation of a horizontal or vertical line on template to be used as an orienting line.

*c.* To determine the coded designation of a point on the map—

(1) Place template on the map so that one reference hole of template, indicated by roman numeral, is over a stated reference point on the map. (Note the code letter of the map, the code number of the reference point, and the code number of the template reference hole.)

(2) Rotate template until orienting line crosses a second reference point on the map. (Note the code number of the second reference point.)

(3) Find the large lettered square in which the point is located.

(4) Find the small numbered square within the large lettered square in which the point is located.

(5) Write code designation as follows:

4267 A 5 Q 100

42 – 1st map reference point used.

67 – 2nd map reference point used.

A – Code name for map.

5 – Code number for template reference hole used.

Q – Template lettered square.

100 – Numbered square within lettered square.

*d.* Knowing the code designation of a point, to locate that point on a map the reverse process is used, as follows:

Given: 2545 C 6 N 63

(1) Use map C.

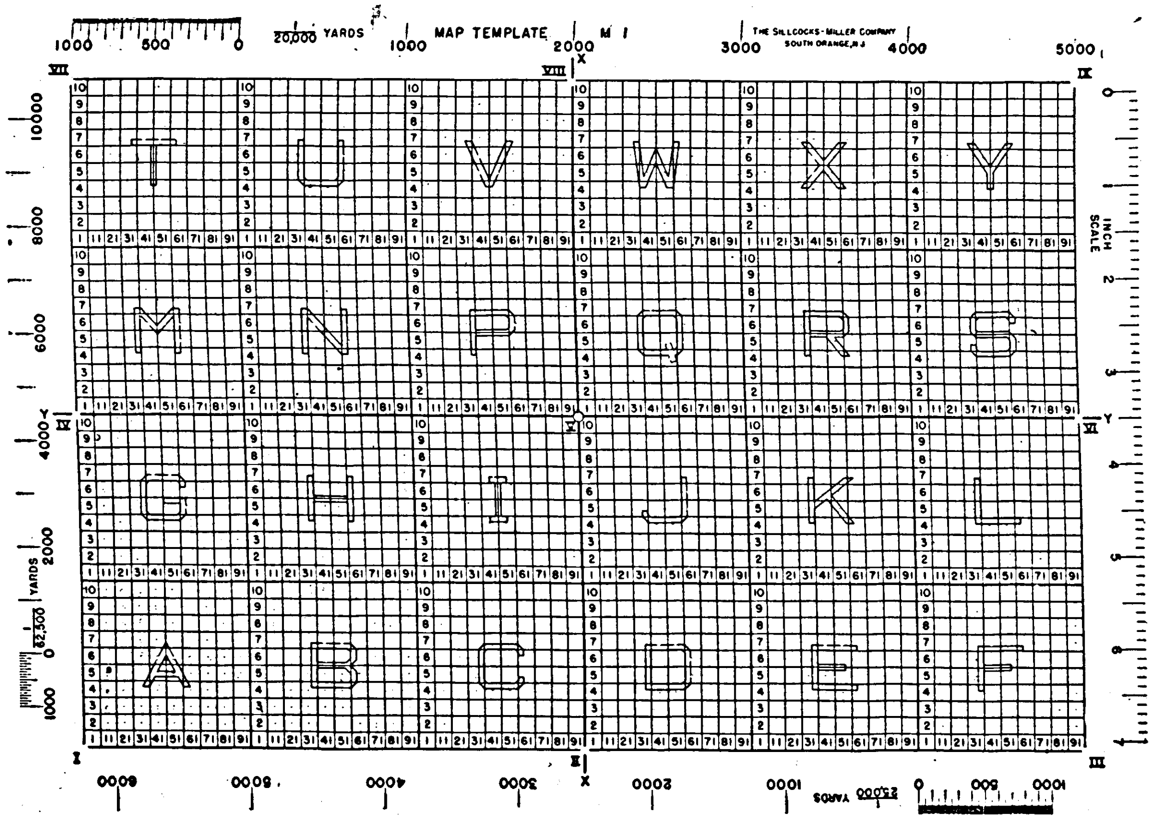



Figure 54. Map template M1.

(2) Place template reference hole 6 over map reference point 25.

(3) Rotate template until orienting line falls on map reference point 45.

(4) Locate lettered square N.

(5) Locate exact point by finding small square 63 within lettered square N.

*e.* For simplicity, the second reference point may sometimes be omitted, and the SOI then states that the horizontal template lines will be placed parallel to the EW grid lines of the map used. This method sacrifices accuracy and security to a moderate degree. For further security the code number for the template reference hole can be designated as the middle (or initial, or final) figure of a three-figure group, in which case a code designation might be transmitted as 2545 C 464 N 63. In this example, the number 6 of the three figure group 464 is the critical code figure referring to the template reference hole.

## Section IX. BRITISH GRID SYSTEM

### 78. Description

*a.* The British Grid system has a basic property which requires that it be broken down into comparatively small areas. This property is the adaptability for accurate surveying without making various grid corrections which are common for large grid areas such as those used in the United States Military grid system. In addition to the areas being rather small they must also be relatively long and slender, with the long axis of the area being either in the direction of a meridian or a parallel. The general shape of a country, continent, or other large area to be gridded usually lends itself to a subdivision in one direction or the other. For example, Netherlands East Indies is easily divided into long slender areas running east and west, while East China is more readily divided into areas running north and south.

*b.* Each area is named as a zone or belt; for example, Netherlands East Indies Zone of Australia Belt No. 5. All British grids are printed in a fixed color throughout any certain zone, the colors for a series of zones being selected so that no two adjacent zones will be in the same color.

*c.* A grid zone is ordinarily divided into squares of 500,000 meters on a side. This basic square is assigned a letter, the letter being alphabetical and reading from left to right and down within a zone. Each 500,000 meter square is further divided into 100,000 meter squares, each

of which is also designated by a letter. Thus a 100,000 meter square of a zone may be identified by two letters. However, some zones are so long that there will be more than one 500,000 meter square assigned the same letter, while in a few zones no letters are used. See figure 55.

*d.* On maps of scales of 1/250,000 to 1/500,000 the letter identifying the 500,000 meter square and the 100,000 meter square letter are both shown on the face of the map. Ordinarily on maps of scales of 250,000 and larger only the 100,000 meter square letters are shown, although the letter identifying the 500,000 meter square may be indicated by a grid index diagram in the margin.

*e.* The frequency of the grid lines is controlled by the scale of the map in question. On maps of scales from 1/20,000 to 1/100,000 the grids are 1,000 meters apart and on smaller scales they are fixed on a 10,000 meter spacing. However, grids on the 1/100,000 scale maps are sometimes on a 10,000 meter spacing.

## 79. Use

*a.* Point identification by grid reference indicates, in order first; the 500,000 meter square, the 100,000 meter square, the abbreviated east-west coordinate, and the abbreviated north-south coordinate. The procedure is as follows:

(1) Indicate the letter identifying the 500,000 meter square, as shown

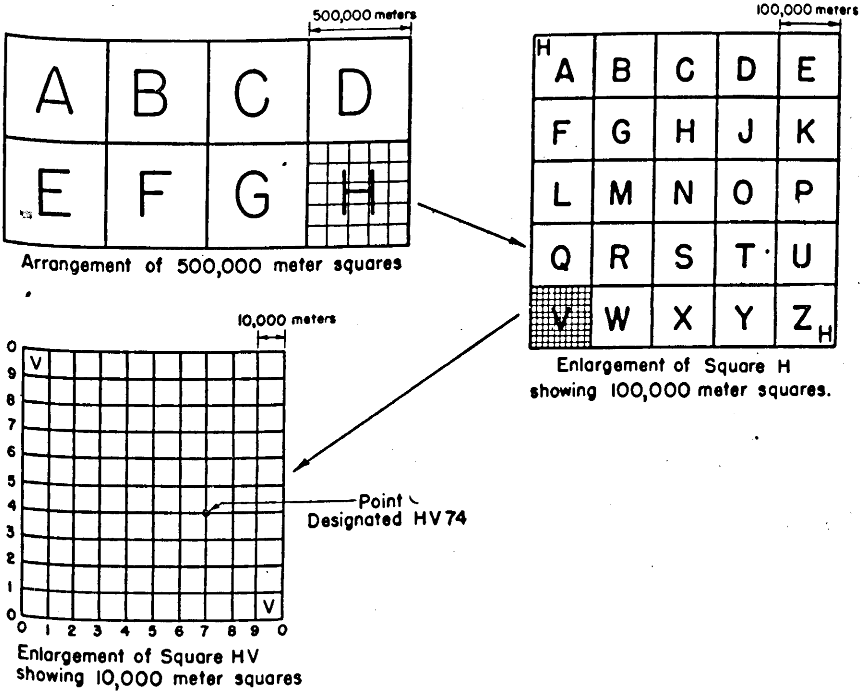



*Figure 55. British grid system.*

directly on the face of the map or as indicated by the grid index diagram.

(2) Indicate the 100,000 meter square as shown on the face of the map, normally by a large open block letter printed in the same color as the grid lines.

(3) Write the east-west coordinate in the same manner as is done in the use of the United States Military grid, omitting the small figure or figures which precede the actual grid number. The grid value will be carried out by estimation or measurement to the minimum value desired. The hyphen or dash between $x$ and $y$ coordinates, always used in the United States Military grid references, is omitted in British grid references. See figure 55 for illustration of point designation.

(4) Write the north-south value in the same manner. The small numbers which precede the large figure at the end of the grid lines represent the total distance from the false origin of the grid coordinates, and are always omitted in point designation.

*b.* British maps and American reproductions of British maps employing the British grid systems, invariably contain at some place in the margin, full instructions for the expression of grid references. In a few British grid zones, the yard is used as a unit instead of the meter. The entire procedure in grid reference, however, is identical in either case.

## Section X. AIR DEFENSE GRID

### 80. General

The purpose of the Air Defense Grid is to satisfy the requirements of air defense in world wide application and to permit easy transmission of accurate positional information. The Air Defense Grid divides and subdivides all the earth's surface to latitude 80° north and south in such a way as to keep the grid divisions and subdivisions approximately square. This is accomplished by changing the size of the grids in degrees and minutes of longitude several times between the Equator and the Poles. The only large variations in shape occur between latitudes 72° and 80° N and S where the top of the grid lines converge considerably toward the poles, but it was felt that due to limited operation in this area it would be less confusing to allow the grids to converge more, rather than to add another change in grid size. Figure 56 illustrates the converging meridians and successive changes in grid lengths.

### 81. Designation

This grid system is based entirely on lines of longitude and latitude

and can be placed on any map having longitude and latitude, regardless of type of projection, as can be seen in figures 57 to 61 where several types are illustrated. The first four successive subdivisions of the grid squares are identified by letters starting from the upper left corner of each grid square and running from left to right consecutively, omitting the letter *I*, as shown in figures 56 to 61 inclusive, and are divided on the basis of degrees and minutes of latitude and longitude. Points in the fifth subdivision are identified by four coordinate numbers, the first two along the $x$ axis (longitude) and the last two on the $y$ axis (latitude). The first digits of the $x$ and $y$ axis are shown on the grid and the second digit of each is estimated.

## 82. First division

The first division of the earth's surface is shown in figure 57 in large shaded block letters:

A – from latitude 60° N to 80° N, longitude 0° around the world to 0°.
B – from latitude 40° N to 60° N, longitude 0° around the world to 0°.

AIR DEFENSE GRID

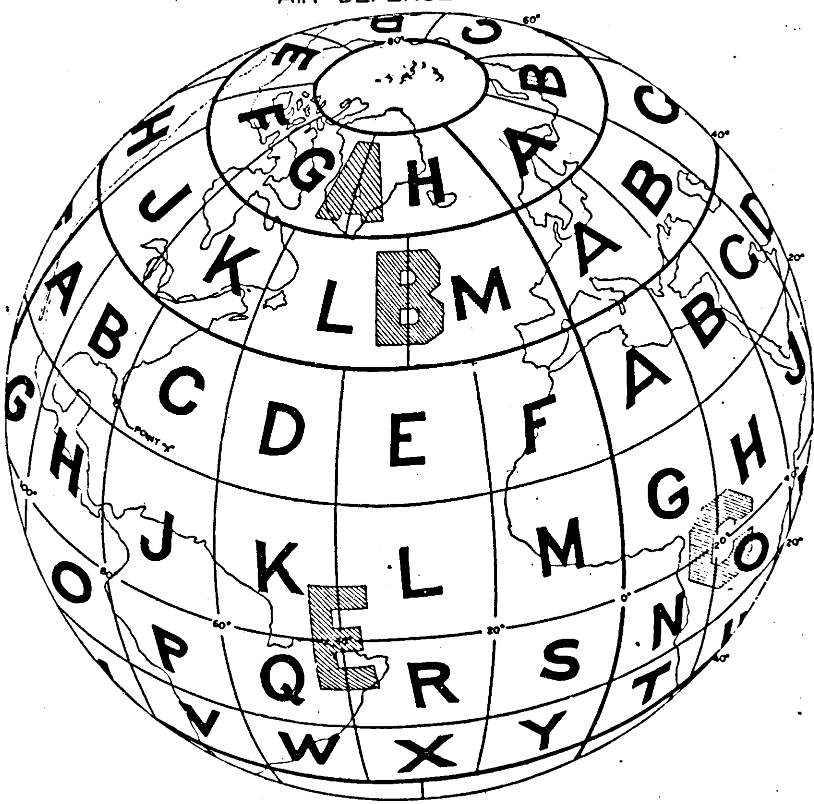


*Figure 56. Spherical presentation of the first and second divisions.*

C – from latitude 40° N to 40° S, longitude 0° to 120° E.
D – from latitude 40° N to 40° S, longitude to 120° E to 120° W.
E – from latitude 40° N to 40° S, longitude 120° W to 0°.
F – from latitude 40° S to 60° S, longitude 0° around the world to 0°.
G – from latitude 60° S to 80° S, longitude 0° around the world to 0°.

## 83. Second division

The second division shown in figures 57 and 58 with solid block letters is a division of each of the above shaded letter divisions as follows:

Shaded letter *A* grid area is subdivided into one row of eight grid squares, lettered from *A* to *H* inclusive. Shaded letter *B* grid area is subdivided into one row of twelve grid squares lettered from *A* to *M* inclusive. Shaded letter *C* grid area is subdivided into twenty-four grid squares, four rows with six grid squares each, lettered from *A* to *Y* inclusive, omitting the letter *I*. Shaded letter *D* and *E* grid areas are subdivided in the same way as shaded letter *C*. Shaded letters *F* and *G* areas are subdivided the same as shaded letters *B* and *A*, respectively.

## 84. Third division

The third division, figure 59, is made by subdividing each one of the

AIR DEFENSE GRID

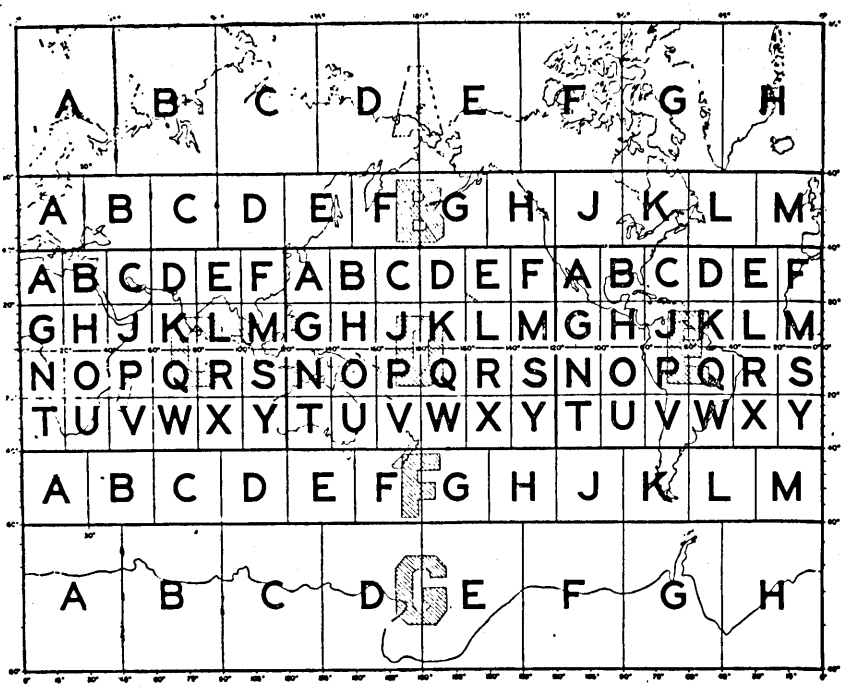



*Figure 57. Division one and division two.*

solid block letter grid squares, made in divisions two into twenty-five grid squares. There are five rows with five grid squares each, lettered with hollow block letters from *A* to *Z*, omitting the letter *I*.

## 85. Fourth division

The fourth division known as basic grid, figure 60, is accomplished by subdividing each one of the hollow block lettered grid squares in division three into twenty-five basic grid squares, five rows with five grid squares in each and lettered from *A* to *Z* inclusive, omitting the letter *I*. The length of sides of the basic grid squares in degrees and statute miles are shown in paragraph 89 and appendix II.

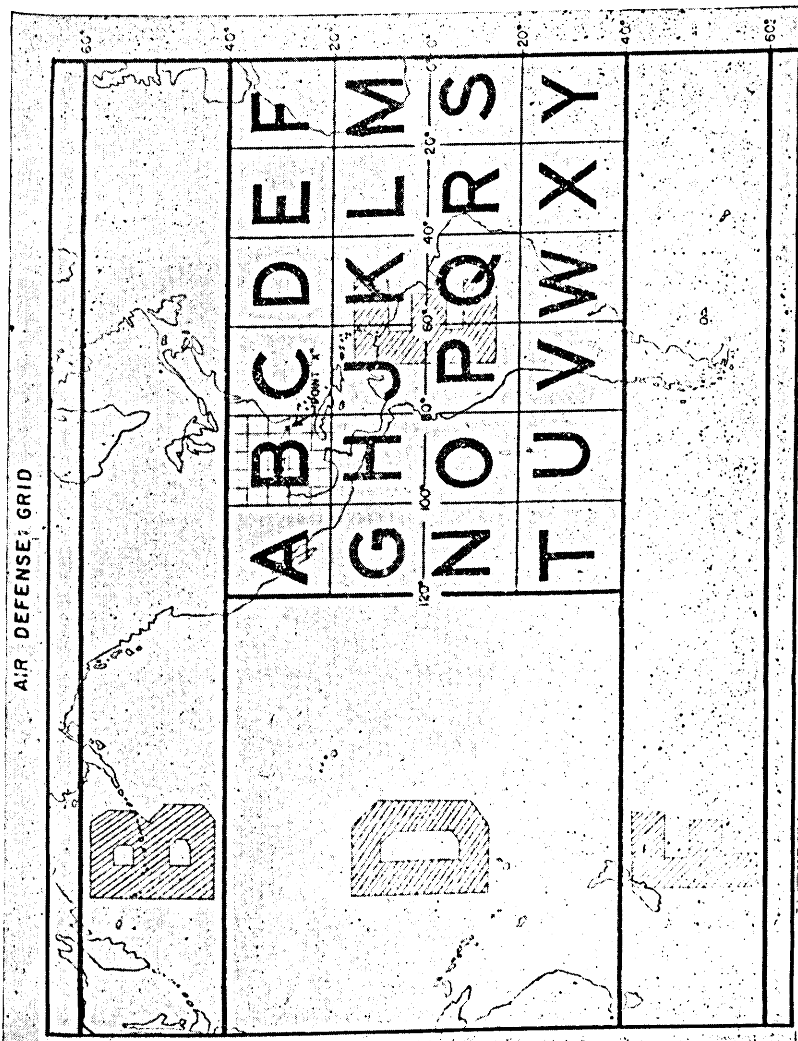



*Figure 58. Division two.*

## 86. Fifth division

The fifth division, figure 61, is made by subdividing each one of the basic grid squares in division four into one hundred squares, ten rows with ten grid squares in each, and numbering the $x$ and $y$ axis. The division can be made by simply stepping off ten equal parts on all four sides of the grid and drawing in the lines parallel to longitude and latitude lines.

## 87. Report

To make a position report the four letters of each of the four divisions, and the four numbers of the fifth division are used. The full designation of point *X*, figure 61, is EBPW 5518. For local operation some of the larger division letters may be omitted.

## 88. Laying out

*a.* To lay out a grid for local operation anywhere between latitude 40° N and S, refer to figure 58 (division two solid block letters) to deter-

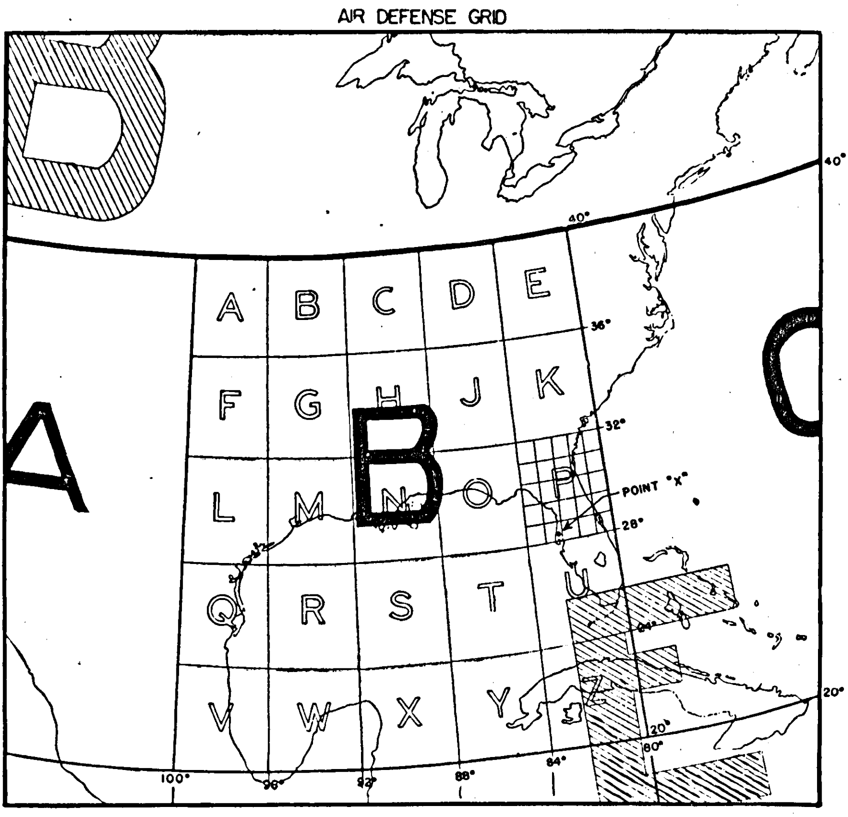



*Figure 59. Division three.*

mine in which grid square the area to be gridded lies. This grid area, 20° on a side, is then laid out with pencil on a map. Next divide this square into twenty-five grid squares 4° on a side and letter the subdivisions as illustrated by hollow letters in figure 59. Only one or two of the division 3 (hollow letter) grid squares are normally used for local operation of the letters. The division three grid square to be used is then divided into 25 basic grid squares, 48′ on a side. Each of these is then further subdivided into 100 grid squares as shown in figure 61.

*b.* The procedure for laying out a grid in the area between latitude 40° and 60° N or S is identical except that the second division grid area

AIR DEFENSE GRID

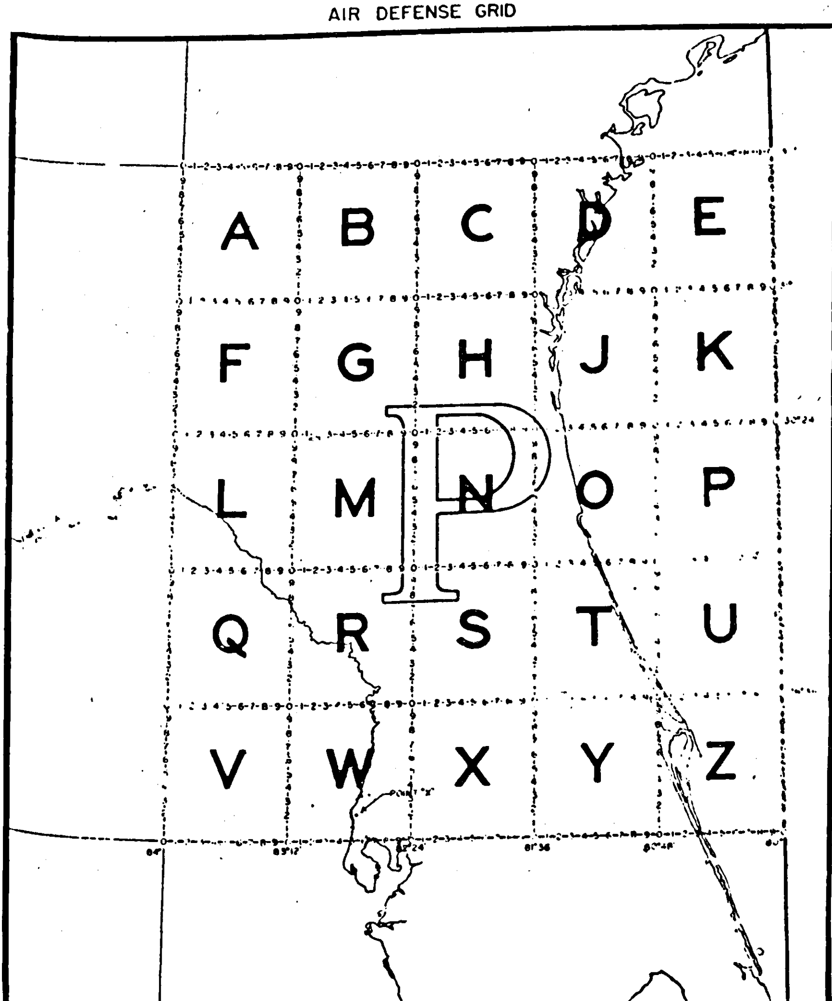



*Figure 60. Division four.*

lengths are 30° longitude by 20° latitude. This makes the third division grid areas 6° longitude by 4° latitude, and the fourth division grid area 72′ longitude by 48′ latitude.

*c*. The procedure is identical for laying out a grid in the area between latitude 60° and 80° N or S except that the second division grid area lengths are 45° longitude by 20° latitude. This makes the third division grid area 9° longitude by 4° latitude, and the fourth division 108′ longitude by 48′ latitude.

## 89. Length of sides

*a*. The following table shows in angular measure the length of the

AIR DEFENCE GRID

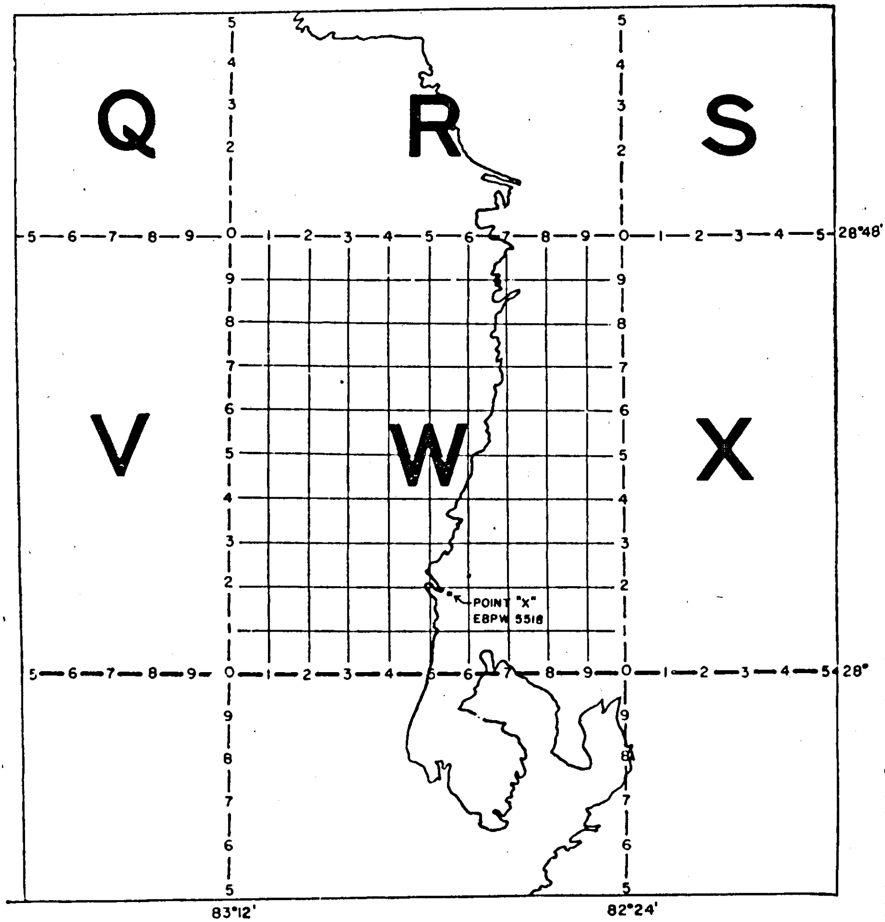



*Figure 61. Division five.*

sides of division 3, and basic grids division 4 in different areas of the world:

| Division one | Latitude | Division 3 | | Division 4 Basic grid | |
|---|---|---|---|---|---|
| (*Shaded letters*) | | *Long.* | *Lat.* | *Long.* | *Lat.* |
| *A & G* | 60° – 80° N & S | 9° | 4° | 108′ | 48′ |
| *B & F* | 40° – 60° N & S | 6° | 4° | 72′ | 48′ |
| *C, D & E* | 40° N – 40° S | 4° | 4° | 48′ | 48′ |

*b.* The following table shows length of basic grid (fig. 60) base lines in statute miles (see app. II also):

| *Latitude Degrees N and S* | | *Miles for 48′ lat.* | *Miles for 48′ long.* | *Miles for 72′ long.* | *Miles for 108′ long.* |
|---|---|---|---|---|---|
| (Equator) | 0 | 54.963 | 55.338 | | |
| | 4 | 54.966 | 55.204 | | |
| | 8 | 54.974 | 54.803 | | |
| | 12 | 54.987 | 54.136 | | |
| | 16 | 55.006 | 53.208 | | |
| | 20 | 55.029 | 52.021 | | |
| | 24 | 55.056 | 50.582 | | |
| | 28 | 55.086 | 48.898 | | |
| | 32 | 55.121 | 46.973 | | |
| | 36 | 55.157 | 44.822 | | |
| | 40 | 55.194 | 42.450 | 63.676 | |
| | 44 | 55.234 | | 59.808 | |
| | 48 | 55.273 | | 55.646 | |
| | 52 | 55.311 | | 51.211 | |
| | 56 | 55.349 | | 46.525 | |
| | 60 | 55.384 | | 41.609 | 62.413 |
| | 64 | 55.417 | | | 54.731 |
| | 68 | 55.446 | | | 46.778 |
| | 72 | 55.472 | | | 38.594 |
| | 76 | 55.493 | | | 30.218 |
| | 80 | 55.509 | | | 21.692 |

For example, the size of a basic grid square at latitude 28° N or S is 55.086 by 48.898 miles. A basic grid square at latitude 48° N or S is 55.273 by 55.646 miles. A basic grid square at latitude 64° N or S is 55.417 by 54.731 miles.

## CHAPTER 6

# METHODS OF DETERMINING POSITION—TRAVERSE

## Section I. GENERAL

### 90. Location of points

*a.* There are three methods of determining the location of a point by means of ordinary surveying instruments: *transit traverse, intersection,* and *resection.* In all three of these methods either the transit may be used and the coordinates computed from the notes, or the plane table may be used and the coordinates scaled from the plot.

*b. Gun positions* are usually selected without regard to known points, and may be in locations not visible to such points, so that it will be impossible to locate the gun position either by resection or intersection and the coordinates will have to be determined by means of a transit traverse.

## Section II. TRANSIT TRAVERSE

### 91. Conduct of traverse

*a.* The nearest point of which the accurate coordinates are known, or can be determined, and from which a route to the point to be located can be followed without great difficulty is chosen from which to start the traverse. In settled communities normally it is possible to follow paths or roads so that very little brush cutting is necessary.

*b. An initial azimuth* must be determined at the starting point. If another point, as distant as possible, but preferably not less than 1 mile distant, of which the accurate coordinates are known, is visible from the starting point, the azimuth can be readily computed. If no point is visible from the starting point, an initial azimuth must be determined by either a solar observation or an observation on a stellar body.

*c.* The traverse must be closed if possible; that is, after reaching the

position to be located, the traverse must either be continued to another known point or run back to the starting point by a different route. The linear error in closure is adjusted throughout the traverse by applying the proper proportion of the error to the points located, according to their distance from the starting point.

*d.* When, because of lack of time the traverse is not closed, another azimuth determination must be made at the end of the traverse to check and adjust the cumulative errors in the transit work; also, the computed position of the point located must be checked as carefully as possible from the map in order to detect any large error that may have occurred in the traverse. In locating a gun position, when the traverse is not closed and time does not permit of azimuth determination at both ends of the traverse, the azimuth preferably is determined at the gun position where it may be used for orienting the gun. In this case the azimuths of the other lines of the traverse must be determined by working backward from the gun position to the starting point.

## 92. Terminology

To avoid using unfamiliar terminology in presenting the subject matter of the paragraphs below, definitions of a few of the more common terms used in surveying are given.

*a.* DIRECT OR NORMAL POSITION OF TRANSIT. When the instrument is so placed that the upper clamp and its tangent screw are nearest the observer, and the focusing screw of the telescope is on top of the telescope. The telescope level bubble tube is below the telescope.

*b.* REVERSED POSITION OF TRANSIT. When the instrument is turned 180° in azimuth from the direct position and the telescope plunged (turned over about the horizontal axis) it is said to be reversed. The direction of pointing is the same, but the telescope level bubble is upside down. This operation is called "reversing the instrument."

*c.* PLUNGING THE TELESCOPE. Inverting the telescope about its horizontal axis.

*d.* TRANSIT STATION. A permanent or semi-permanent point set in the ground. It marks an angle point or corner in a traverse, but may also be used to prolong a preceding course. The purpose is usually accomplished by driving a stake in the ground, a tack being set in the top of the stake to mark the exact point. This is done by the front rodman or chainman, or under his direction. For temporary transit stations, a nail driven into the ground through a piece of paper may be used.

*e.* TRIANGULATION STATION (Δ). As used in this manual, a permanent reference point with known coordinates, either military grid or geographic.

*f.* FORESIGHT. Pointing the telescope on the next station of the traverse.

*g*. Backsight. Pointing the telescope on the last preceding station of the traverse, usually with the telescope "plunged."

## Section III. ORGANIZATION AND DUTIES OF TRANSIT TRAVERSE PARTY

### 93. General

A transit party for the running of a traverse should consist of an instrumentman in charge, a recorder, two chainmen, and two rodmen. In case of necessity, one of the chainmen may also perform the duties of front rodman and the instrumentman may act as his own recorder.

### 94. Duties of instrumentman and recorder

*a.* The *instrumentman* is in charge of the party and is responsible for the carrying through of the traverse. Before running the traverse he gives careful consideration to the necessary precision of the results required, studies the terrain, and selects the best route to his objective. Time is usually the controlling factor in the degree of accuracy attainable. If time is available, measurements of distance are made by tape, but if speed is essential, stadia measurements may be used. The instrumentman sets up and levels the transit and measures off the angles of the traverse and checks the measured distance to the last station by a stadia reading. Occasionally he reads the magnetic bearing of a traverse line as a check against a large mistake in reading or recording angles in the traverse.

*b.* The *recorder* is responsible for keeping the records of the traverse in the field notebook. These records must be legible and clear, and must follow the form indicated in paragraph 102. He gets the distances between stations from the chainman if the tape is being used, or from the instrumentman if stadia is used. He keeps a rough sketch of the traverse showing distances and angles, as he goes along. This sketch serves as a check on the values recorded in his notes. In addition to keeping these notes he renders such assistance to the instrumentman as the latter may direct.

### 95. Duties of front rodman

The front rodman sets his rod over the next transit station as indicated by the chainmen, plumbs it, and waits until given the signal by the instrumentman that he is ready to proceed to the next station. He marks the station, and then proceeds to the next station, which has, in

the meantime, been measured by the chainmen. If the stadia is being used instead of tape, he sets up at positions indicated by the instrumentman.

## 96. Duties of the rear rodman

The rear rodman sets his rod over the last station vacated by the transitman, plumbs it, and waits until given the signal by the instrumentman that the latter is through with him. He then picks up his rod and proceeds to the station occupied by the transit, identifies this station, and sets up and plumbs his rod as soon as the transit has been set up at the next successive station. The instrumentman, if ready to proceed before the rear rodman arrives, may mark the station position for him. The rear rodman usually carries a stadia rod which is used to check the distance measured by the tapemen. He holds his stadia rod with the narrow edge toward the transit when the transitman is reading angles. On a prearranged signal from the instrumentman he faces the stadia rod toward the transit so that the distance may be read. If using stadia-measured distances alone, tapemen are unnecessary.

## 97. Duties of the tapemen

*a.* The tapemen carry the following equipment: 1 steel tape (usually 100 feet in length), 11 marking pins or arrows, 1 plumb bob, a number of nails, a pencil, and a writing pad. The tapemen, before measuring the distance to the next station, pick out a point on which to align themselves. The rear tapeman then holds his end of the tape at the last station (now marked by the front rodman's rod) and aligns the front tapeman up with the selected point. The front tapeman makes certain the tape is straight and tight, and then puts a marking pin in the ground at the 100-foot mark. He then proceeds toward the next station pulling the tape with him until the rear tapeman, who is holding the other end of the tape, calls out that he has reached the marking pin. The front tapeman then aligns himself with the last marking pin and the front rodman's rod and puts down another marking pin. The rear tapeman then picks up his marking pin and they both proceed to measure another 100 feet length.

*b.* Transit stations are located at even tape lengths, when convenient, in order to simplify the work of the computer. They are selected at points affording not only an unobstructed view back to the transit but also a clear view forward to the next station. Each station is marked as described in paragraph 92*d*. One tapeman then goes ahead to locate the next station while the other tapeman stays by the station just measured until the front rodman has arrived and located it.

*c.* In locating transit stations the tapemen must bear in mind that it is desirable for the instrumentman to be able to see the lower part of the rod when sighting. This is especially important on short sights, for

errors due to sighting the upper part of a rod which is out of plumb may appreciably affect the accuracy of the line.

*d.* Before beginning a measurement, the front tapeman checks his marking pins and makes certain he has ten; the eleventh pin occupies the last station. At the end of the measured line, he counts the number of pins he has left and subtracts from 10. He then checks with the rear rodman who should have the difference, one pin being always in the ground. This double check may appear unnecessary, but errors of 100 feet in measured distances due to careless checking of pins are not uncommon. If the front and rear tapemen do not agree on the measured distance, it is remeasured.

*e.* When the ground has a decided slope, it is necessary that one end of the tape be held above the ground in order that the tape is horizontal. A plumb bob is used to refer the elevated end to a point on the ground. Very steep slopes require "breaking" the tape.

*f.* Errors in measuring are generally due to failure to keep the tape horizontal and to careless plumbing. Tapemen must understand that the accuracy of the traverse depends on their work just as much as on the instrument work.

## Section IV. TRANSIT TRAVERSE PROCEDURE

### 98. Initial data required

*a.* General. Before beginning the computation of a transit traverse it is necessary that certain information be available. Generally, this consists of the coordinates of some station on the traverse and the azimuth of a line from some station on the traverse. When using military grid coordinates, it is also necessary to know the latitude and longitude of a midpoint of the traverse in order to determine the correction for magnification of scale if a very precise survey is being made. The starting point and the route of the traverse are often influenced by the required information.

*b.* Coordinates. The military grid coordinates of some prominent point in the vicinity are frequently available. Lacking such data, the grid coordinates of some known point established by some higher headquarters or the Corps of Engineers are usually available. These data should be supplied by the staffs of higher commands. In cases where coordination with other artillery units dictates the use of local plane coordinates, the coordinates are obtained from the reconnaissance officer of the other unit.

*c.* AZIMUTH. When two intervisible known points or triangulation stations have military grid coordinates or latitude and longitude known, the military grid azimuth from one of these stations to the other can be computed. This obviates an astronomical determination of azimuth. If two intervisible stations, whose local plane coordinates are known, are available, the grid azimuth (local plane) can be computed. Lacking conditions where two known intervisible stations are available, military grid azimuth or local plane grid azimuth is determined astronomically.

## 99. Measurement of angles

*a.* The standard method of measuring the angles in a transit traverse is the deflection angle method. In this method deflection angles between the lines of the traverse are measured instead of direct angles. The method of measuring deflection angles may be understood by referring to figure 62.

*b.* In figure 62, *A*, *B*, and *C* represent stations 1, 2, and 3, respectively, of a transit traverse. The deflection angle between the line *AB* (station 1 to 2) and line *BC* (station 2 to 3) is the angle *PBC*; that is the angle between *AB* prolonged and *BC*. This also represents the difference between the azimuth *AB* and *BC*. The direct angle between *AB* and *BC* is the angle *ABC*, which is the supplement of the deflection angle. The method of measuring this deflection angle is as follows and is the procedure at each station:

(1) Set up and level the transit over station *B*.

(2) Set the *A* vernier to read zero. Invert or plunge the telescope and, using the lower motion turn the telescope to sight on the preceding station *A*.

(3) Plunge the telescope to the normal position and note whether the next station is to the right or left of sight. ~~Then, *using the upper motion only*, direct the telescope on the next station *C* and record the reading of venier *A*.~~ C1 If the station is on the right, the deflection angle is plus, if on the left it is minus. This is entered in the notes as well as shown on the sketch of the traverse kept by the recorder.

(4) Leaving the upper motion clamped, loosen the lower motion, and turn the telescope to sight again on the preceding station *A*, *using the lower motion only*, and clamp.

(5) Loosen the upper motion, plunge the telescope and direct it on the forward station *C*, *using the upper motion only*. Read and record vernier *A*. This completes the measurement of the deflection angle, giving two readings, one read with the telescope direct and the other with the telescope reversed. The last reading, divided by two, is the angle used and should check the first reading within 1 minute if the transit is in good adjustment. More accurate results can be secured by repetition of this operation, making six measurements of the deflection angle, three with the transit erect on the backsight and three with

the transit reversed. Dividing the last reading by six should give an average angle that is accurate to $1/6$ minute.

(6) At the initial station of the traverse, or wherever the orienting line is to be obtained, the deflection angle between the forward station and the orienting line is measured.

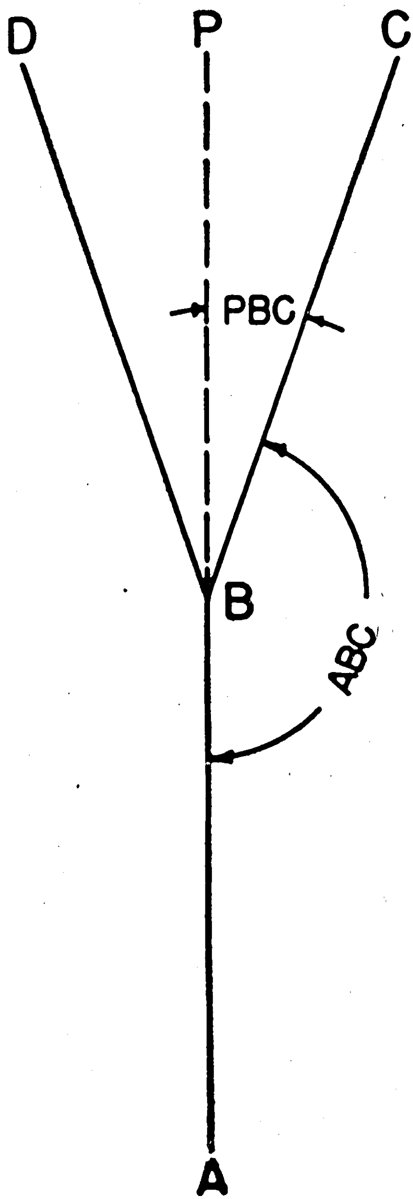



*Figure 62. Diagram of angle.*

(7) If, when the transit was set up at $B$ (fig. 62) and pointed at $A$, the vernier $A$ reading was zero, and after the telescope has been plunged and pointed on $C$ the same vernier read 15°, the deflection angle $PBC$ should then be an angle of $+ 15°$. If the azimuth of $AB$ was 5°, the azimuth of $BC$ ($C$ being to the right of $BP$) should be $5° + 15° = 20°$.

(8) If station number 3 was $D$ instead of $C$ and the angle $DBP$ was 15°, the second vernier reading would have been —15°, and the azimuth of $BD$ would be $5° — 15° = 350°$.

*c.* Assuming that the orienting line has been established at station 1, the instrumentman sets his transit up over station 1 and measures the deflection angle between the orienting point and station 2. This operation establishes the azimuth of the leg from station 1 to station 2. He proceeds to station 2 and measures the deflection angle between the line from station 1 to station 2, prolonged and station 2 to station 3, etc.

*d.* Another method of measuring the angles in a transit traverse is that of *direct angle measurements.* This method consists simply in measuring the angle in a clockwise direction at each station directly from a backsight on the preceding station to the station ahead. If desired the angle may be doubled, or repeated any number of times. It is customary to measure the angle by repetition when accurate work is desired. Care must be taken not to read the wrong angle as is easily possible in such a case as station $C$, in figure 63. However, by always measuring the angle in a clockwise direction, mistakes are obviated. In this figure, let $A$ represent a triangulation station and $D$ a directing point ($DP$) at the gun position whose position is to be determined. The transit is set up at $A$, the angle to $AB$ from some reference line of known azimuth is read, and the distance to station $B$ is determined by tape measurement and checked by stadia. The transit is taken to $B$ and the interior angle between the courses $AB$ and $BC$ is measured and the distance to $C$ is determined. $C$ is occupied in a similar manner. To check the work, the traverse is made to close by returning to the starting point, $A$, by another route, which in this case includes one additional station, station $E$. Method of procedure at each station:

(1) Set up and level the transit over the stake marking the station.

(2) Using the upper motion, clamp vernier $A$ to *0°*.

(3) With the telescope in the direct position, direct the line of sight on the preceding station with the lower motion, using the lower slow motion screw to make precise setting, and clamp. At the first station it is necessary to measure the angle between the line to the forward station and a line whose azimuth is known in order to secure the data for computing the azimuths of the courses of the traverse.

(4) If using stadia, read and record the intercept on the rod and the corresponding vertical angle.

(5) Loosen the upper motion and direct the telescope on the forward station with the upper slow motion, and clamp.

(6) Read and record vernier *A*. In very accurate work, the angle must be measured by repetition; that is, the angle is measured several times and the mean of the readings used.

(7) Read and record stadia intercept and vertical angle to the forward station.

## 100. Measurement of distances

*a.* The distance between points on the traverse is measured in two ways; by use of the steel tape as described in paragraphs 51 and 52, or by stadia. It is suggested that a combination of both methods be used, the stadia distance being used only as a check on the distance measured with the tape. This sometimes prevents the introduction of a larger error in chaining into the traverse calculations.

*b.* If distances are being measured by stadia only, the instrumentman and recorder must bear in mind that on slopes the vertical angles must be read and stadia distances converted to horizontal distances by the use of table VI, TM 5-236.

# Section V. FIELD NOTES

## 101. General

There are several different recognized methods of keeping field notes for transit traverse. Any system that is easily kept and easily read is satisfactory, but the best form of field notes is a combination of the

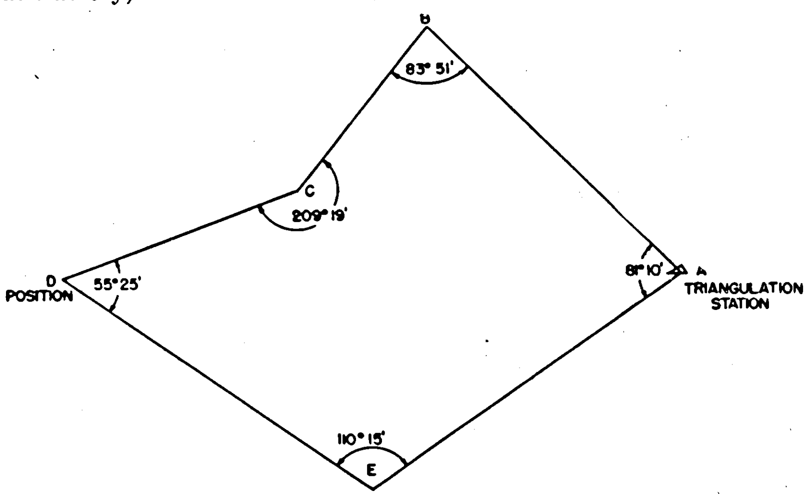



*Figure 63. Direct angle traverse.*

tabular and the sketch book type of notes. In this system the ordinary field notebook is used. One page of the book is used to keep the notes in a tabular form as shown in the following paragraph, the page directly opposite in the notebook is used to make a simple field sketch of the transit traverse as it progresses. In this way a check is made of the note keeping and the making of large mistakes is prevented.

## 102. Example of field notes

*a.* Traverse from No. 7 to gun directing point (*DP*) military grid coordinates of No. 7: $X =$ 675,578.0

$Y =$ 1,580,779.5 Zone "A"

Latitude 37° 00′N. Longitude 76° 18′ 24″ W.

pencil

| Station (1) | Distance (2) | Reading Vernier *A* (3) | Deflection Angle (4) | Grid Azimuth (5) | Remarks (6) |
|---|---|---|---|---|---|
| Azimuth No. 7 to Station 1, computed from observation | | | | ° ′<br>115 24 | |
| 1 | 1,200 ft. | ° ′<br>0 00<br>41 45<br>83 30 | ° ′<br>—41 45 | 73 39<br>73 40 | (Adj. Brg.) |
| 2 | 1,900 ft. | 0 00<br>45 43<br>91 26 | +45 43 | 119 22<br>119 24 | Magnetic bearing S 54° 45′ E<br>(Adj. Brg.) |
| 3 | 2,250 ft. | 0 00<br>17 20<br>34 40 | +17 20 | 136 42<br>136 45 | (Adj. Brg.) |
| 4 | 1,500 ft. | 0 00<br>11 35<br>23 10 | +11 35 | 148 17<br>148 21 | (Adj. Brg.) |
| Azimuth Sta. 4 to Sta. 5, computed from observation | | | | 148 21 | |
| 5<br>DP | 23 ft. | 0 00<br>5 00<br>10 00 | — 5 00 | 143 21 | |

NOTE: No. 7 is backsight for station 1. Distance No. 7 to Station 1 is 870 ft. Foresight from station 5 was taken on the gun directing point (DP). Adj. Brg. means adjusted bearing.

(The field sketch for this traverse is shown in fig. 64.)

*b.* Column (1) contains the number of the station occupied. Column (2) contains the distance from the station occupied, to the next station.

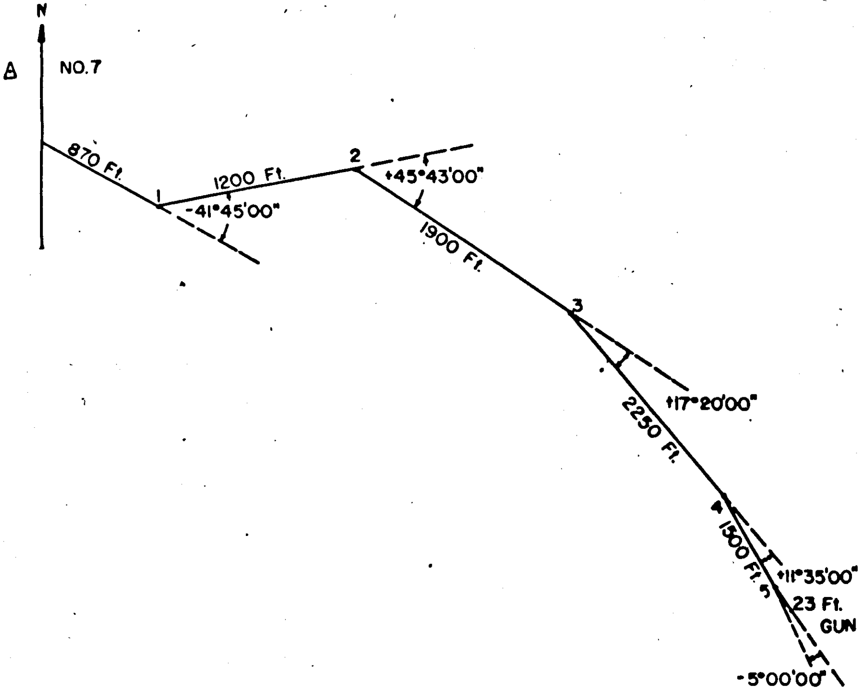



*Figure 64. Field sketch of traverse.*

For example, distance station 1 to station 2 is 1,200 feet measured by tape and checked by stadia. Column (3) contains the reading of *A* vernier. The first number is zero, the original setting before the angle is measured. The second number is the first reading of the vernier, the transit being in the direct position. The third number is the second reading of the vernier, the transit being in the reversed position. Column (4) contains the deflection angle which is the average of the two deflection angles measured. This average is secured by dividing the third number (3) by two. The proper sign is given this angle; plus (+) is the angle measured to the right, minus (—) is measured to the left. Column (5) contains the calculated grid azimuth. The number at the top of the column is the grid azimuth from No. 7 to station 1, computed from astronomical observation. The upper line opposite each station is the unadjusted azimuth and the lower line is the adjusted azimuth. The unadjusted azimuth is determined by applying the deflection angle with its proper sign to the azimuth of the last station. The adjusted azimuth is obtained in the manner explained in the paragraph 104. Column (6) is for remarks. A careful reading of the transit compass needle should be made at frequent intervals and recorded opposite the proper station in this column. This will serve as an approximate check on the azimuths of column (5).

## 103. General

In the computation of a traverse, it is sufficiently accurate for orientation of mobile batteries to use the adjusted value of the azimuths to the nearest minute, and to use five-place logarithms or natural functions. Any error thus introduced will be compensating, and the computation is facilitated. The adjustments may be smaller than 1 minute, in which case the adjustment only serves to indicate whether to use the next higher or next lower minute. In cases where the result becomes exactly 30″ the angle is selected to the nearest *even* minute; for example, 27′ 30″ is used as 28′, while 28′ 30″ is also used as 28′. This serves to distribute any accumulated error that might develop by another method. It must be kept in mind that for a more precise traverse all angles are measured by repetition, and the angles and adjustments are carried to seconds. Such precision entails a greater expenditure of time and effort and is usually unwarranted for the orientation of a mobile battery and so is not advocated in this manual.

## 104. Proportioning azimuth errors

In the example of a transit traverse in paragraph 102, it was assumed that an astronomical observation for azimuth was taken at each end of the traverse for which the field notes are shown. The total adjustment is divided equally between the angles measured.

| | ° | ′ |
|---|---|---|
| Unadjusted azimuth, station 4 to 5 | 148 | 17 |
| Observed azimuth, station 4 to 5 | 148 | 21 |
| Error | | 4 |
| Error per station (four) | | 1 |

In this case the adjustment is made by adding 1′ to the azimuth of station 1 to 2, 2′ to the azimuth of station 2 to 3, 3′ to the azimuth of station 3 to 4, and 4′ to the azimuth of station 4 to 5. The adjusted azimuth is placed immediately below the unadjusted azimuth in Column (5) and is to be used in the computation of coordinates. In a normal battalion traverse of about 16 stations, the error of closure should not exceed 4′. In a traverse of 16 stations the error is divided by 16 and each angle is adjusted 1/16 of the total error.

## 105. Calculation of bearing ($\beta$)

In the computation of the $\Delta x$ and $\Delta y$ increments, the measured station-to-station distance is the hypotenuse of a right triangle the legs of which are the desired $\Delta x$ and $\Delta y$ values; the angle used in solving each right triangle to obtain the $\Delta x$ and $\Delta y$ increments for each successive station must be the azimuth itself in quadrant 1 (see fig. 65), 180° — azimuth

in quadrant 2, azimuth — 180° in quadrant 3 and 360° — azimuth in quadrant 4. It is obvious from the sketch that the resultant value is the bearing angle $\beta$, either east of west of north, or east or west of south.

## 106. Calculation of $\Delta X$ and $\Delta Y$

*a.* By referring to figure 65, which is merely a handy diagram for showing the algebraic value of $\Delta x$ and $\Delta y$, the sign of $\Delta x$ and $\Delta y$ may be determined.

*b.* Take the first traverse line in the transit traverse used as an example in the previous paragraphs. This line has an azimuth of 115° 24′ and a length ($D$) of 870 feet. Figure 65 shows that the azimuth 115° 24′, is in the second quadrant and that $\Delta x$ is EAST, while $\Delta y$ is SOUTH in this quadrant. ~~The question in this quadrant shows that~~

$+\Delta x = D \sin B$

$-\Delta y = D \cos B$

(1) Using the value 180° 00′ —115° 24′ or 64° 36′ for the value of $\beta$ as directed above:

$+\Delta x = 870 \sin 64° 36' = 785.9$

$-\Delta y = 870 \cos 64° 36' = 373.2$

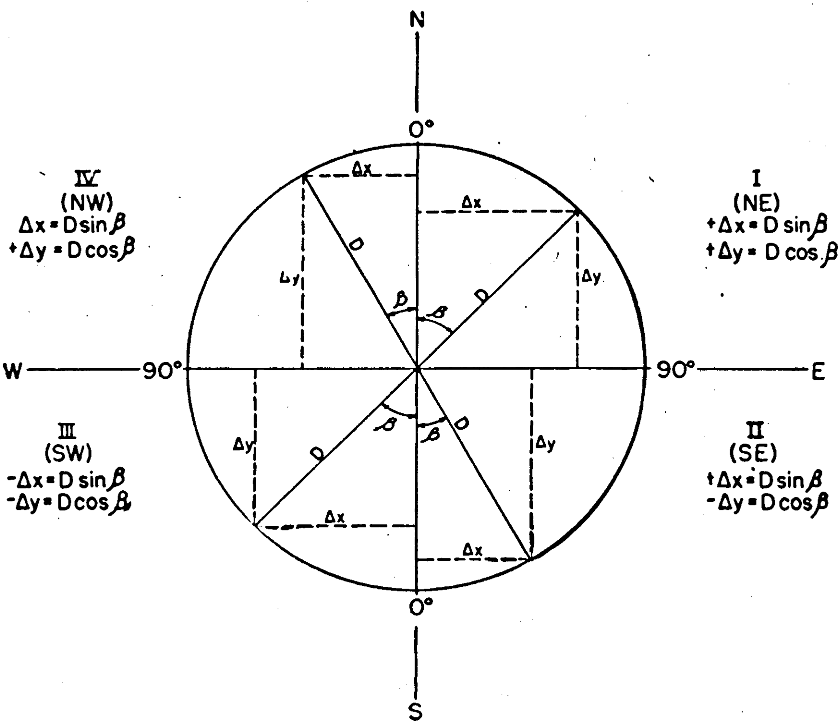



*Figure 65. $\Delta x$ and $\Delta y$ diagram for solution of transit traverse.*

(2) The value for $\Delta x$ is entered in a column marked EAST and the value for $\Delta y$ is entered in a column marked SOUTH.

(3) Each line of the traverse is calculated and the resultant $\Delta x$ and $\Delta y$ is entered into the proper column.

*c.* The use of five-place trigonometric functions is sufficiently accurate for computation of a transit traverse.

### 107. Error of closure

In order to determine the $\Delta x$ and $\Delta y$ errors it is necessary that the traverse either close on itself or close on a point whose coordinates are known. The error can then be determined. If the traverse closes on itself the sum of the $\Delta x$ values and likewise of the $\Delta y$ values must equal zero. If closure is made on a point whose coordinates are known, the difference between the known coordinates and the computed coordinates is the error of closure. The error of closure having been determined, unless there is good reason to the contrary, the error of closure in $\Delta x$ is distributed among the individual measurements in the proportion of their value to the $\Delta x$ of the traverse. The same type of distribution is made for the $\Delta y$ error of closure.

## Section VII. TRAVERSE TABLES

### 108. General

A traverse may be solved by plane trigonometry as shown in the previous example, by traverse tables, or by construction. Traverse tables are available in TM 1–208, or 4–238. Traverse tables provide an expeditious method of solving a traverse distance to determine the latitude and departure or $\Delta Y$ and $\Delta X$ distance. Traverse tables are made up in pages of bearings for each degree from 1° to 89°. To compute the latitude and departure for a given distance and bearing, the page of traverse tables having a bearing corresponding to the bearing of the traverse line, is used. The measured distance is then located on the page, and the latitude and departure is listed alongside the distance. A bearing of degrees and minutes requires interpolation between pages for solution.

### 109. Example

Assume that the first leg of the traverse shown in paragraph 102 is to be solved by means of a traverse table in TM 1–208. The given bearing is S 64° 36′ E and the distance is 870 feet. Turn to the traverse tables

corresponding to 64° (p. 132, TM 1-208). The distances listed are only from 1 to 600; therefore, 870 will be the sum of 600 and 270. For bearing 64°

| | | |
|---|---|---|
| Departure for distance | 600 | = 539.3 |
| Departure for distance | 270 | = 242.7 |
| Departure for distance | 870 | = 782.0 |
| Latitude for distance | 600 | = 263.0 |
| Latitude for distance | 270 | = 118.4 |
| Latitude for distance | 870 | = 381.4 |

For bearing 65°

| | | |
|---|---|---|
| Departure for distance | 600 | = 543.8 |
| Departure for distance | 270 | = 244.7 |
| Departure for distance | 870 | = 788.5 |
| Latitude for distance | 600 | = 253.6 |
| Latitude for distance | 270 | = 114.1 |
| Latitude for distance | 870 | = 367.7 |

For bearing 64° 36′

$$\text{Departure} = 0.6 \times (788.5 - 782.0) + 782.0 = 785.9$$
$$\text{Latitude} = 381.4 - 0.6\ (381.4 - 367.7) = 373.2$$

Since the bearing was S 64° 36′ E the departure is 785.9 East and latitude 373.2 South which was the same as results by trigonometric calculation.

# CHAPTER 7

# METHODS OF DETERMINING POSITION—INTERSECTION

## Section I. GENERAL

### 110. Definition

Intersection is a simple form of triangulation used to locate an unknown, unoccupied point, from two or more known points. It gets its name from the intersection, at the unoccupied point, of the lines of sight from known points. The intersection may be calculated trigonometrically with data secured by use of the transit, or graphically with the plane table. It can also be solved graphically on a plotting board with the data secured by the transit. Solving the problem mathematically resolves itself into the solving of an oblique plane triangle having two known angles and the included side.

### 111. Use

Intersection is commonly employed in running a traverse either by transit or plane table, or to locate an auxiliary point off the traverse without the necessity of measuring the distance to it. It is frequently an advantageous way to save time or to locate an inaccessible point.

### 112. Base line

The accuracy with which a point may be located by intersection depends upon the precision of measurement of the base line, the effective length of the base line, and the precision of the measurement of the two angles. For artillery purposes the base line must be of such length that the angle subtended by it at the unknown point is not less than 10 degrees. Obviously the nearer the subtended angle is to 90° the more accurate the results. When locating a point off of a traverse, one of the traverse lines is frequently used as the base line, the angles to the unknown point being measured from each end of the traverse line. For all practical purposes the ordinary accuracy with which the traverse lines are measured will suffice for any intersections made off the traverse line. For very accurate results the base line is measured with all precision and care possible, and the angles measured by "repetition."

## 113. Field work

The field work necessary in locating a point by intersection is very simple, comprising the measurement of the angles from the known points to the point to be located, and the determination of the distance between the two points occupied. The measuring of the angles has been described previously. The distance between the two occupied points is usually measured when running the traverse itself, or can be measured by tape or stadia.

*a.* To provide a check against the calculation and the plotting, and also against a faulty identification of the object sighted upon, it is always well to make an intersection with three rays instead of two. That is, intersection angles are read from three known stations to the unknown station. The directions from at least two of the stations should, if practicable, form a large angle of intersection at the point to be located.

*b.* In selecting the points to be occupied the instrumentman pays particular attention to the proper proportion of the angle subtended at the unknown point, *P*. He selects the points on the traverse that will make both measured angles approximately 45° and of such value as make the angle at the unknown point as close to 90° as possible. He tries to pick out points that give a clear, unobstructed view of the point, *P*, and if possible, intervisible points.

*c.* If it is not possible to measure the angles from each end of a traverse line, the angles may be measured from any angle point in the traverse. This condition is called a "broken" base line and necessitates more calculation to establish the coordinates of the unknown point. There is also more chance for angular error as more angle points are brought into the calculations. An example of intersection using a broken base line is given in section III.

## 114. Field notes

The field notes necessary in an intersection problem comprise a tabulated form showing the series of measurements of the angles with the final result, together with a fairly accurate sketch. The sketch shows the location of the stations on the base line and the unknown point, *P*, and it is well to sketch in the value of the measured angles. This procedure is of great value in computing the coordinates of point, *P*, if the tabulation is not clear to the calculator.

## 115. Solution of problem—Azimuth and length of base line known

*a.* Here are given the calculations performed in establishing the coordinates of an unknown point, *P*, by means of angles measured to *P* from the two ends of a base line (the two ends being intervisible, the coordinates known, and the azimuth and length of the base line also being known). This is the simplest type of intersection problem and one widely used in locating the directing points of gun batteries.

*b.* Given the coordinates of two known points:

| | *X* | *Y* |
|---|---|---|
| *A* | 677,976.1 | 1,580,907.0 |
| B | 678,074.6 | 1,580,951.5 |

Latitude 37° N. Length *A* to *B* = 108.07 yards

Azimuth *AB* 65° 43′ Longitude 76° 18.4′ W. (Ft. Monroe, Va.)

The transit was set up at *A* and *B* and the following angles were measured by repetition to point *P* whose coordinates were unknown:

Angle BAP = 40° 20′ 00″

Angle ABP = 50° 10′ 00″

*Required:* The coordinates of *P*.

*First step:* Since azimuth of base line *A* to *B* is 65° 43′ bearing of line *A* to *P* is 65° 43′ —40° 20′ = 25° 23′ and bearing of line *B* to *P* is (65° 43′ + 180°) + 50° 10′ = 295° 53′. Then angle *APB*, the angle at the unknown point, *P*, is 180° — (40° 20′ + 50° 10′) = 89° 30′.

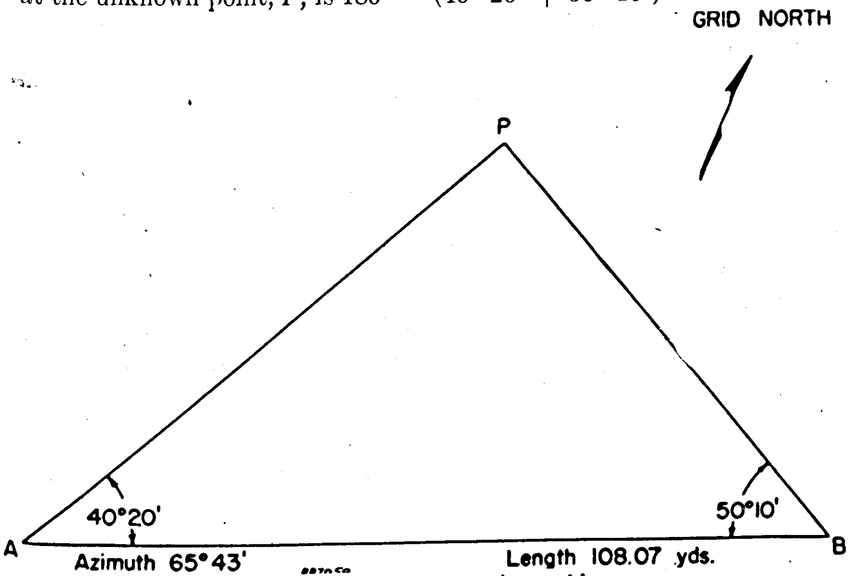



*Figure 66. Typical intersection problem.*

~~Length of line A to P is, by the law of sines:~~

see c1

$$AP = \frac{\text{distance } AB}{\text{sin angle } APB} \times \text{sin angle } ABP$$

and the length of line $B$ to $P$ is

$$BP = \frac{\text{distance } AB}{\text{sin angle } APB} \times \text{sin angle } BAP$$

By logarithms:

Distance $A$ to $P$:

| | | | |
|---|---|---|---|
| Log $A$–$B$ | = | 2.03371 | |
| Log sin $APB$ | = | 9.99998 | |
| | | 2.03373 | |
| Log sin $ABP$ | = | 9.88531 | |
| Log $A$–$P$ | = | 1.91904 | |
| $A$–$P$ | = | | 82.99 yards |

Distance $B$ to $P$:

| | | | |
|---|---|---|---|
| Log $A$–$B$ | = | 2.03371 | |
| Log sin $APB$ | = | 9.99998 | |
| | | 2.03373 | |
| Log sin $BAP$ | = | 9.81106 | |
| Log $B$–$P$ | = | 1.84479 | |
| $B$–$P$ | = | | 69.95 yards |

*Second step*: The azimuth of line $A$ to $P$ is 25° 23′, length 82.99 yards. Next we must calculate the $\Delta x$ and $\Delta y$ of point $P$ from point $A$. The bearing $B$ of line $A$ to $P$ being in the first quadrant is N 25° 23′ E.

Solving for $\Delta x$ and $\Delta y$ we have—

$\Delta x$ point $P$ = distance $A$–$P$ $\times$ sin 25° 23′ and $\Delta y$ of point $P$ = distance $A$–$P$ $\times$ cos 25° 23′.

By logarithms:

| | | | |
|---|---|---|---|
| Log $A$–$P$ | = | 1.91904 | |
| Log sin $B$ | = | 9.63213 | |
| Log $\Delta x$ | = | 1.55117 | |
| $\Delta x$ | = | | 35.58 yards |
| Log $A$–$P$ | = | 1.91904 | |
| Log cos $B$ | = | 9.95591 | |
| Log $\Delta y$ | = | 1.87495 | |
| $\Delta y$ | = | | 74.98 yards |

$\Delta y$ must be corrected for magnification of scale. For a latitude of 37° and longitude of 76° 18′ 24″, this correction is (from table XLIX, TM 5–236) 1.068 yards per thousand.

Correction $y$ = .075 $\times$ 1.068 = .08 of a yard. Corrected $y$ = 74.98 + .08 = 75.06 yards.

*Third step:* We now have the $\Delta x$ and $\Delta y$ of point $P$ from point $A$. To establish the coordinates of point $P$, inasmuch as the bearing to point

$P$ is in the first quadrant, we add these values, $\Delta x$ and $\Delta y$, to the coordinates of point $A$.

| | $X$ | $Y$ |
|---|---|---|
| Coordinates of point $A$ | 677,976.1 | 1,580,907.0 |
| $\Delta x$ and $\Delta y$ of point $P$ | 35.58 | 75.06 |
| Coordinates of point $P$ | 678,011.68 | 1,580,982.06 |

In order to check the coordinates of point $P$ and the calculations used in establishing the coordinates, we can perform the same calculations from point $B$.

The azimuth of point $P$ from point $B$ is 295° 53′. The bearing, $B$, then is 360° —295° 53′ = 64° 07′ and being in the fourth quadrant is N 64° 07′ W.

Solving for the $\Delta x$ and $\Delta y$ of the point $P$ from point $B$ we have:

$$\Delta x \text{ of point } P = \text{distance } B\text{–}P \times \sin B$$
$$\Delta y \text{ of point } P = \text{distance } B\text{–}P \times \cos B$$

By logarithms:

| | | | |
|---|---|---|---|
| Log $B$–$P$ | = | 1.84479 | |
| Log sin $B$ | = | 9.95409 | |
| Log $\Delta x$ | = | 1.79888 | |
| $\Delta x$ | = | | 62.93 yards |
| Log $B$–$P$ | = | 1.84479 | |
| Log cos $B$ | = | 9.64002 | |
| Log $\Delta y$ | = | 1.48481 | |
| $\Delta y$ | = | | 30.54 yards |

As before, $\Delta y$ must be corrected for magnification of scale. The correction is 1.068 yards per thousand.

Correction $\Delta y$ = .030 × 1.068 = .03 of a yard.

| | | |
|---|---|---|
| $\Delta y$ | = | 30.54 |
| Correction $\Delta y$ | = | .03 |
| Corrected $\Delta y$ | = | 30.57 yards |

We have now the $\Delta x$ and $\Delta y$ of point $P$ from point $B$. To establish the coordinates of point $P$, inasmuch as bearing $B$ to $P$ is in the fourth quadrant, we subtract the $\Delta x$ from coordinates of point $B$ and add the $\Delta y$ (corrected) to coordinates of point $B$.

| | $X$ | $Y$ |
|---|---|---|
| Point $B$ | 678,074.60 | 1,580,951.5 |
| $\Delta x$ and $\Delta y$ of point $P$ | —62.93 | +30.57 |
| | 678,011.67 | 1,580,982.07 |

## 116. Solution of problem—coordinates of base line known

*a.* Another type of intersection met with in the field is quite similar to the first problem calculated above. Here only the coordinates of the

two known points are given. The two points are intervisible and are at each end of a traverse line. Below is given the computation solving a problem of this type.

*b. Given:* The coordinates of two known points:

| | X | Y |
|---|---|---|
| A | 1,437,896.0 | 1,585,450.0 |
| B | 1,438,669.0 | 1,585,666.0 |

Latitude 37° 00′ N. Longitude 76° 30′ W. Zone *B*.

A transit was set up at *A* and *B* and the following angles were measured by repetition on to point *P* whose position was desired:

Angle *BAP* = 66° 15′ 30″

Angle *ABP* = 67° 28′ 00″

*Required:* The coordinates of *P*.

*First step:* Determine azimuth and length of line *AB*.

| | X | Y |
|---|---|---|
| A | 1,437,896.0 | 1,585,450.0 |
| B | 1,438,669.0 | 1,585,666.0 |

$\Delta x$ = 773.0 $\Delta y$ = 216.0 (uncorrected)

Correction for magnification of scale for point at latitude 37° north and longitude 76° 30′ west is from table XLIX TM 5–236, 1.967 yards per thousand yards. 1.967 × .216 = .42, or .4 yards.

Therefore $\Delta y$ corrected = $\Delta y$ = 216.0

—Correction = .4

Corrected $\Delta y$ = 215.6 yard

$$\text{Tangent bearing of AB} = \frac{\Delta x}{\Delta y} = \frac{773.0}{215.6}$$

Log 773.0 = 2.88818

Log 215.6 = 2.33365

Log tangent bearing = .55453

Bearing *AB* = 74° 24′ 56″ East of North

Grid azimuth of *AB* = 74° 24′ 56″

AB = $\Delta x$/sine bearing =

Log $\Delta x$ = 2.88818

Log sin 74° 24′ 56″ = 9.98373 —10

Log *AB* = 2.90445 (*AB* = 802.50)

*Second step:* Solution by way of side *AP*.

By law of sines *AP*/sin *B* = *AB*/sin *P*, or *AP* = *AB* × sin *B*/sin *P*.

Solving for *AP:* The solution for this problem is the same as for the previous problem in paragraph 115 from this point on.

## 117. Solution—"Broken" base line

*a.* A third and a more unusual problem is sometimes encountered in rough or broken country in which the unknown point, *P*, can be seen

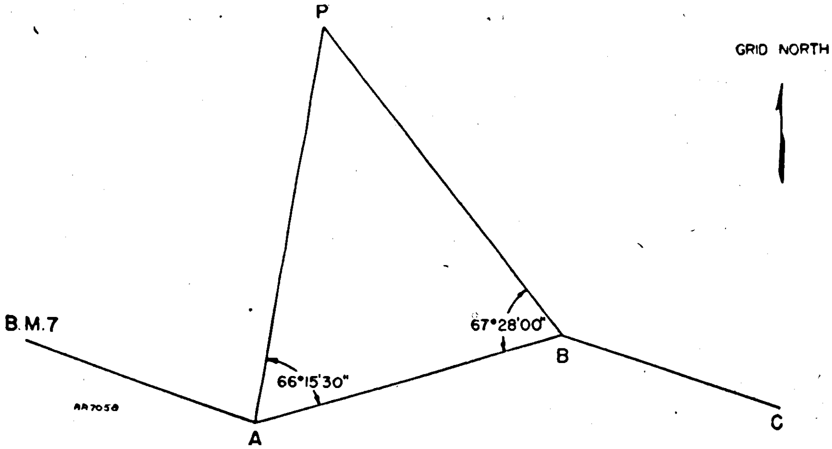


*Figure 67. Intersection as part of a traverse.*

only from two points that are not intervisible but are part of the same traverse. Figure 68 shows the field sketch giving the data measured and calculated in a problem of this type.

*b.* (1) This problem is called intersection by means of a "broken" base line and is quite similar to the other two problems, the only difference is that the two angles are measured from points that are not visible from each other in the traverse, as shown in figure 68. Angle *PBC* is measured from *C* to *P* with transit at *B*, and angle *PED* is measured from *P* to *D* with transit at *E*.

Since the bearings of the lines in the traverse are known or can be calculated from their coordinates, the bearings of the two lines *B* to *P* and *E* to *P*, can be calculated.

(2) The next step is that of calculating the length and bearing of a

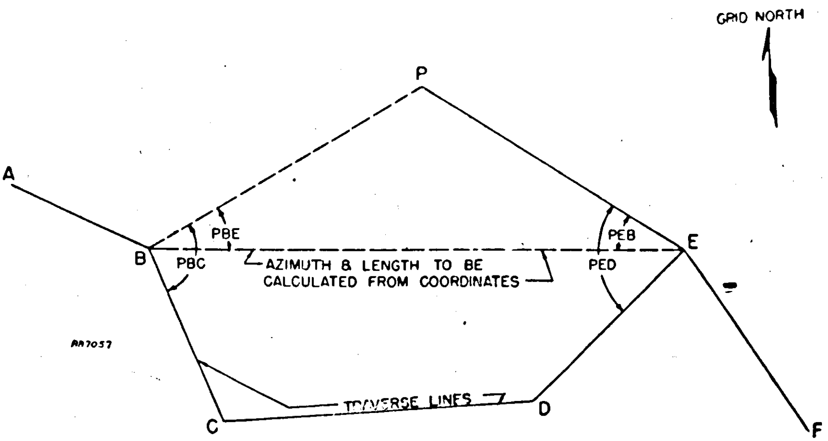


*Figure 68. Broken base line.*

line connecting point $B$ to point $E$. This is done as in example in paragraph 115 from their coordinates. With the bearing of $B$ to $E$ known and the bearings of the two lines $B$ to $P$ and $E$ to $P$ known, the two included angles $PBE$ and $PEB$, can be secured by subtraction of the bearings of the calculated line from the bearings of the two lines to point $P$.

(3) From this point the problem is the same as problem in paragraph 115, the solving of an oblique plane triangle with the two angles and the included line (calculated) given.

## Section IV. GRAPHICAL SOLUTION OF TRANSIT INTERSECTION

### 118. Plotting board solution

In locating the unknown point, $P$, by means of angles measured with a transit it is sometimes desired to locate point $P$ only approximately. This is done by means of a plotting board and protractor. On a plotting board, using coordinate paper, line $A$ to $B$ is laid off to scale. Using a protractor, the angle $ABP$ is laid off from point $A$ and a line of indefinite length drawn out from point $A$. The angle $ABP$ is then laid

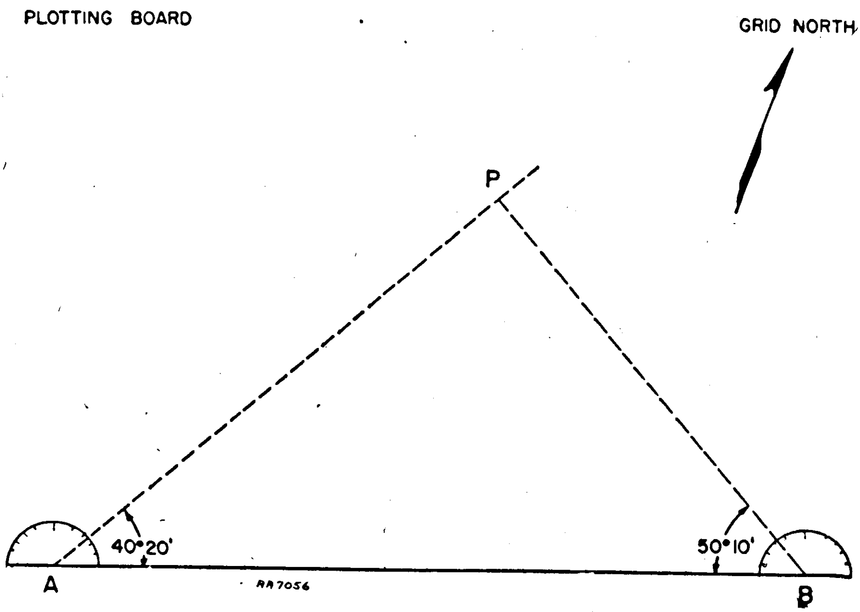



*Figure 69. Graphical intersection.*

off from point $B$ and a line drawn from that point to the intersection of the line from point $A$. This intersection is the desired point $P$. The coordinates can be scaled or read off the plot, the bearings of lines $A$ to $P$ and $B$ to $P$ can be read with the protractor and distances $A$ to $P$ and $B$ to $P$ scaled off with a scale. (See fig. 69 for graphical solution of problem in par. 115.)

# CHAPTER 8

# METHODS OF DETERMINING POSITION—RESECTION

## Section I. GENERAL

### 119. General

*a.* Resection is a method that may be used for determining the location of a point from which three known points can be seen. It has the advantage of requiring only one set-up and that is at the point whose location is desired. It is occasionally used to locate a point from which to start a traverse. Because of the nature of an observation post, it often affords a convenient way of locating such a post. Its use in locating a gun position is seldom practicable unless it is used to locate a starting point for the traverse which is surveyed to locate the gun position, as the gun position is usually hidden from sight.

*b.* Resection is the reverse of intersection. While in intersection it is necessary to occupy at least two known points and sight on the unknown point which is not occupied, in resection the unknown point itself is the only point occupied, sights usually being taken on three known points, from which the name "three-point problem" is derived.

*c.* Resection can be used advantageously to determine the grid coordinates of a point to be used as a starting point for a traverse, when the known points or bench marks are at a considerable distance from the projected traverse or the known points are inaccessible. Under such conditions, it might be possible to apportion the work of orientation so that one party can conduct the resection problem at the same time as the traverse is being performed by another party.

*d.* Resection can be performed by use of the plane table and graphical methods, but it is inadvisable for artillery fire to be based on such methods, unless the time permitted is insufficient for a mathematical solution of the resection problem. Graphical methods are useful for a quick approximate solution but are normally too inaccurate for use in orientation of a gun battery.

*e.* The three-point problem may be solved if three well-defined points, for which the grid coordinates are known, are visible from the location of the point for which grid coordinates are desired, and some means are

provided for measuring the angle between each of the three points from the point selected.

*f*. The problem in paragraph 120 illustrates the method of solution. This problem is solved by using only basic rules of geometry and trigonometry and for this reason the reconnaissance officer need remember only the basic geometric and trigonometric theorems and formulas and not the form of solution or the order of the solution. If the fundamentals of the problem are remembered, any variations presented in a field condition are easily solved without the necessity of using reference books or standard forms that may not be available when needed.

## Section II. SAMPLE PROBLEM

### 120. Problem

A battalion of AA guns is to be moved into a position very soon. The battalion reconnaissance officer has a gridded map and a transit available. He decides to run a traverse from some point for which he has the grid coordinates to the directing points and observation stations of the gun batteries. However, any points on the map for which he can obtain grid coordinates are at a considerable distance or inaccessible, making it impossible to run a traverse to a known point in the time

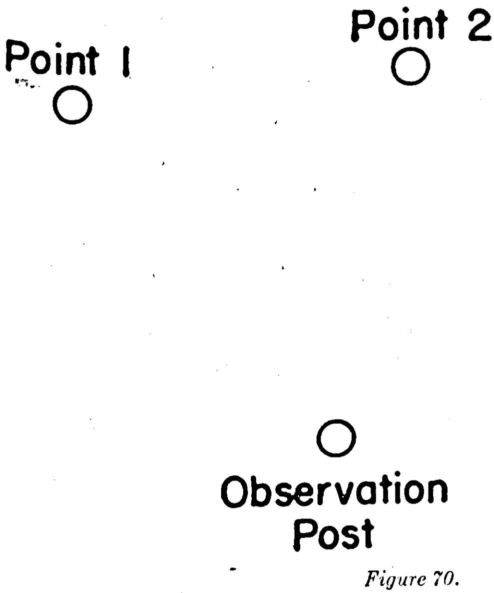



*Figure 70.*

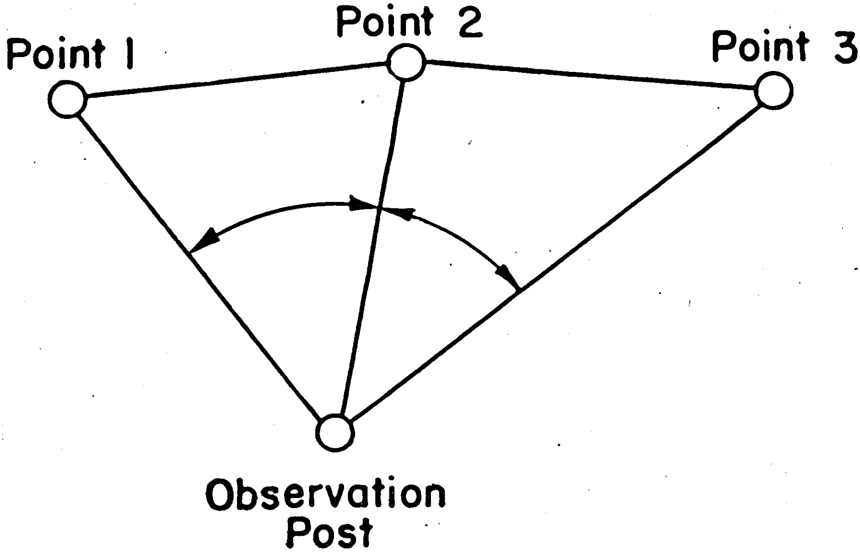


*Figure 71.*

permitted for orientation. After looking over the terrain, he finds that there are three points, with known coordinates, visible from one observation station. He sets up the transit over this point and measures the angles by repetition between the first and second point and the second and third point. The map location is as shown in figure 70. Figure 71 shows the problem presented with the angles measured. The problem is now solved by using the basic fundamentals of geometry and trig-

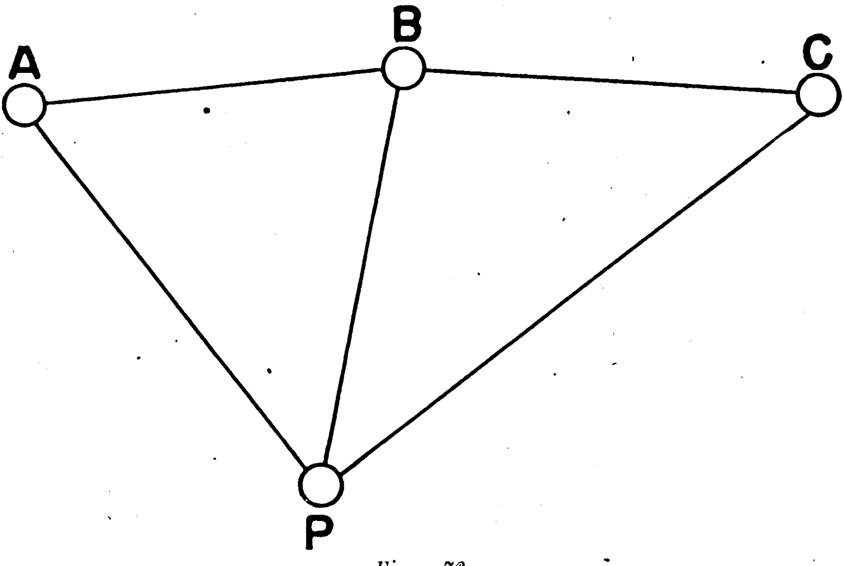


*Figure 72.*

onometry as follows: For convenience, letter the points in any way to designate specific points and angles. (See fig. 72.)

The following data are now known:

| Point | Grid coordinates | |
|---|---|---|
| | *X* | *Y* |
| *A* | 702762 | 974103 |
| *B* | 700811 | 975476 |
| *C* | 698835 | 977302 |

Angle $APB$ = 47° 48′ 40″
Angle $BPC$ = 42° 55′ 10″
(Approximate latitude 32° 00′ N; longitude 91° 45′ W; zone *C*.)

Describe a circle through points *A*, *C*, and *P* (see fig. 73) and draw a straight line from *P* through *B* and continue it until it intersects the circle. (A rough drawing is sufficient as all measurements are computed and not scaled.)

NOTE: If points *A*, *B*, *C*, and *P* should fall on the same circle, the solution is indeterminate and some other known point should be used instead of either *A*, *B*, or *C*.

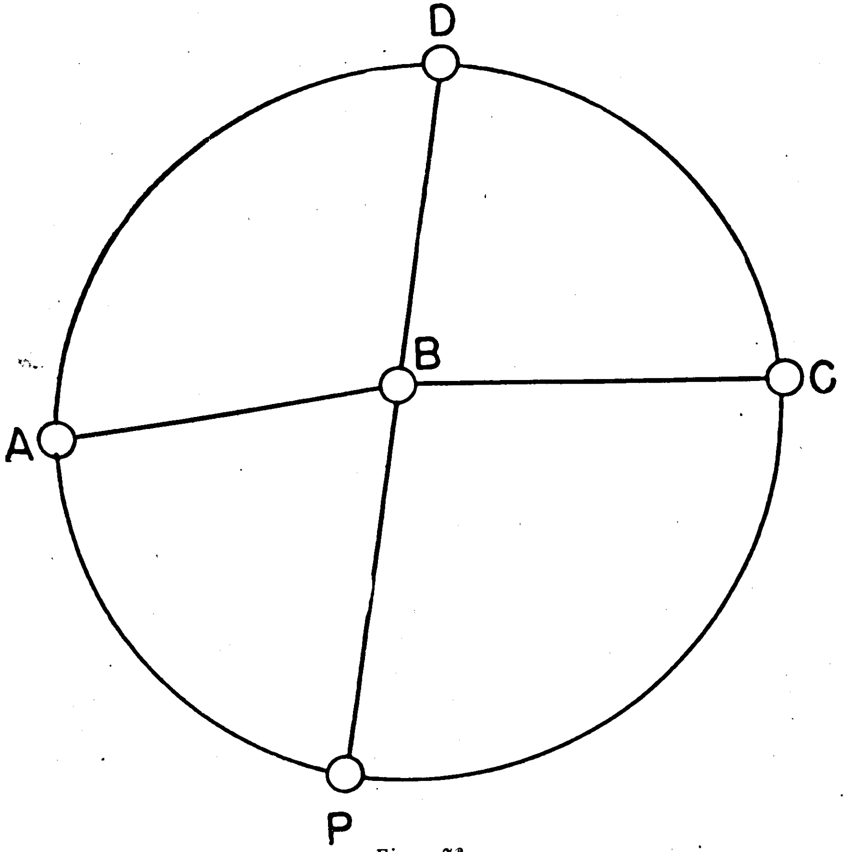



*Figure 73.*

Construction lines are drawn to connect all points as shown in figure 74.

$\angle APB = 47° 48' 40''$ (measured by transit)

$\angle BPC = 42° 55' 10''$ (measured by transit)

$\angle APB = \angle ACD$ (All angles inscribed in the same segment of a circle are equal.)

$\angle BPC = \angle DAC$ (same as above)

I. Length and azimuth of $BA$

| | | |
|---|---|---|
| $X$ of $A$ | = | 702762.0 |
| $X$ of $B$ | = | 700811.0 |
| $\Delta x$ | = | 1951.0 |
| $Y$ of $A$ | = | 974103.0 |
| $Y$ of $B$ | = | 975476.0 |
| $\Delta y$ | = | 1373.0 |

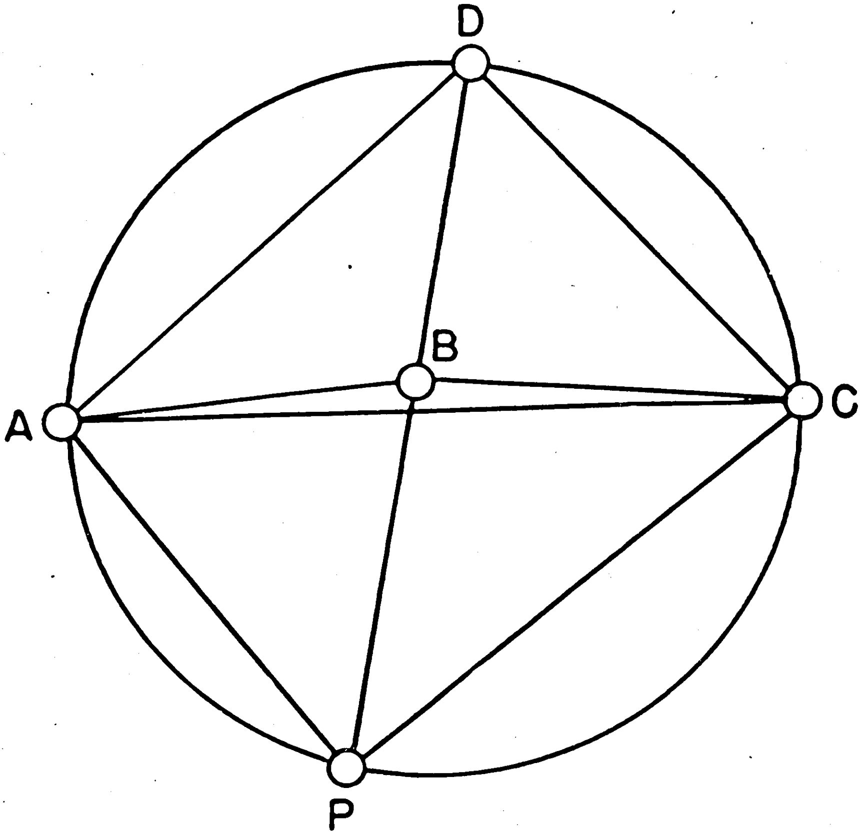



*Figure 74.*

(Table XLIX, TM 5–236.)

Mag. correction $= \dfrac{.685 + .986}{2} = .835$

$\Delta y$ correction $= .835 \times 1.373 = -1.1$

Corrected $\Delta y$ = 1371.9

Log 1951 ($\Delta x$) = 3.29026

Log 1371.9 ($\Delta y$) = 3.13732 (subtract)

Log tan bearing = 0.15294

bearing = 54° 53′ 11″

~~azimuth = 125° 06′ 49″~~

(180° — bearing)

$BA$ = $\Delta x$/sin bearing

Log $\Delta X$ = 3.29026

pre cl

Log sin 54° 53′ 11″ = 9.91276 (subtract)

Log $BA$ = 3.37750

$BA$ = 2385.1

II. Length and azimuth of $CA$

pre cl

$X$ of $A$ = 702762.0

$X$ of $C$ = 698835.0

$\Delta y$ = 3927.0

$Y$ of $A$ = 974103.0

$Y$ of $C$ = 977302.0

$\Delta x$ = 3199.0

Mag. correction $= \dfrac{.685 + .986}{2} = .835$

$\Delta y$ correction $= .835 \times 3.199 = -2.7$

Corrected $\Delta y$ = 3196.3

Log 3927 ($\Delta x$) = 3.59406

Log 3196.3 ($\Delta y$) = 3.50465 (subtract)

Log tan bearing = 0.08941

bearing = 50° 51′ 23″

azimuth = 129° 08′ 37″

(180° — bearing)

$CA$ = $\Delta x$/sin bearing

Log $\Delta X$ = 3.59406

Log sin 50° 51′ 23″ = 9.88962 (subtract)

Log $CA$ = 3.70444

~~$CA$ = 5063.4~~

III. Length $AD$

$\angle CDA$ = 180° — (42° 55′ 10″ + 47° 48′ 40″) = 89° 16′ 10″

$AD = \dfrac{AC \sin ACD}{\sin ADC}$ (sine law)

Log $AC$ = 3.70444

Log sin 47° 48′ 40″ = 9.86978

Log = 3.57422

Log sin 89° 16′ 10″ = 9.99996 (subtract)

Log $AD$ = 3.57426

$AD$ = 3752.0

IV. Angle $ADB$

$a.$ $\angle BAD = 42° 55' 10'' - \angle BAC$

$\angle BAC$ = Azimuth $CA$ — Azimuth $BA$

$= 129° 08' 37'' - 125° 06' 49''$

$= 4° 01' 48''$

$\angle BAD = 42° 55' 10'' - 4° 01' 46'' = 38° 53' 24''$

$b.$ Length $BD$

$$\overline{BD}^2 = \overline{AD}^2 + \overline{AB}^2 - 2 \times AB \times AD \times \cos BAD \text{ (cosine law)}$$

$$\overline{BD}^2 = (3752.0)^2 + (2385.1)^2 - 2 \times 2385.1 \times 3752.0 \times \cos 38° 53' 24''$$

Log 3752.0 $= 3.57426$
$\times 2$
Log $\overline{AD}^2 = 7.14852$
$\overline{AD}^2 = 14{,}077{,}400$

Log 2385.1 $= 3.37750$
$\times 2$
Log $\overline{AB}^2 = 6.75500$
$\overline{AB}^2 = 5{,}688{,}500$

Log 2 $= 0.30103$
Log 2385.1 $= 3.37750$
Log 3752.0 $= 3.57426$
Log cos $38° 53' 24'' = 9.89118$
Log $= 7.14397$
Value $= 13{,}930{,}600$

$\overline{BD}^2 = 14{,}077{,}400 + 5{,}688{,}500 - 13{,}930{,}600 = 5{,}835{,}500$

Log 5,836,300 $= 6.76606$
$\div 2$
Log $BD = 3.38303$
$BD = 2415.6$

$c.$ Sin $\angle ADB = \dfrac{AB \sin BAD}{BD}$ (sine law)

Log 2385.1 $= 3.37750$
Log sin $38° 53' 24'' = 9.79784$ (add)
Log $= 3.17534$
Log 2415.4 $= 3.38303$ (subtract)
Log sin $ADB = 9.79231$
$ADB = 38° 18' 26''$

V. Length $BP$

$a.$ In triangle $ADP$

$\angle$ DAP $= 180° - (\angle ADP + APD)$
$= 180° - (\angle ADB + APB)$
$= 180° - (38° 18' 26'' + 47° 48' 40'')$
$= 93° 52' 54''$

$b.$ $\angle BAP = \angle DAP - \angle BAD$
$= 93° 52' 54'' - 38° 53' 22''$
$= 54° 59' 32''$

$BP = \dfrac{BA \sin BAP}{\sin BPA}$ (sine law)

Log 2385.1 $= 3.37750$
Log sin $54° 59' 32'' = 9.91332$
Sum logs $= 3.29082$
Log sin $47° 48' 40'' = 9.86978$ (subtract)
Log $BP = 3.42104$
$BP = 2636.6$

Azimuth $BP$ = Azimuth $BA - \angle ABP$
$\angle ABP = 180° - (\angle BAP + \angle APB)$
$= 180° - (54° 59' 32'' + 47° 48' 40'')$
$= 77° 11' 48''$
Azimuth $BP = 125° 06' 49'' - 77° 11' 48''$
$= 47° 55' 01''$
Bearing $BP = 47° 55' 01''$ (E of N)

pu C1

| | |
|---|---|
| ~~$\Delta x = BP \sin$ bearing~~ | ~~$\Delta y = BP \cos$ bearing~~ |
| Log $BP = 3.42104$ | Log BP $= 3.42104$ |
| Log sin bearing $= 9.87051$ | Log cos bearing $= 9.82620$ |
| Log $\Delta X = 3.29155$ | Log $\Delta Y = 3.24724$ |
| $\Delta X = 1956.8$ | $\Delta Y = 1767.0$ |
| $X$ of $B = 700811.0$ | Mag of scale corr. $(1.767 \times .835) = +1.5$ |
| $X$ coor. of $P = 702767.8$ | $1768.5$ |
| | $Y$ of $B = 975476.0$ |
| | $Y$ coor. of $P = 977244.5$ |

The above solution involves only the solution of oblique triangles having two sides and one angle or two angles and one side given. The geometric principle used is that all angles inscribed in the same segment of a circle and subtending the same chord are equal. The remainder of the problem is a matter of deduction as to which known parts may be used to solve for the unknown parts. Another approach to the same method is given in paragraph 126, TM 5–235.

## Section III. SUMMARY

### 121. Comparison of methods

It has been customary in the past to present the orientation problem as a collection of uncoordinated methods, with the result that the student arrived at the conclusion that some rule (which he did not know) established the method of orientation to be used in the field. For example, the methods of traverse, intersection and resection, were taken up one by one. The student seldom could see any interrelation between the three. Actually, each method has a special advantage over the other in some particular way. ~~If the reconnaissance officer realized the advantage of each method over the other, he is able to work to better advantage in the field.~~ pu C1

### 122. Traverse

Traverse is a slow laborious method requiring the survey party actually to travel and measure the distances over all parts of the traverse. In heavily wooded or rough terrain the expenditure of time in making a traverse is prohibitive. But, in places where only one point is visible or for establishing a base line, or for connecting a local point to a point of known position the method of traverse is ideal.

## 123. Intersection

Intersection is relatively fast but depends on a base line of known length. Also, two points must be visible from the instrument. However, if a line of known length is available or has been measured by traverse and the other end of this base line is visible, it is possible to determine the position of any visible point very quickly from this one point. It is possible by this method to determine position of points to be used by resection.

## 124. Resection

Resection requires that three points are visible from the occupied point and that the position of these points be known. However, if three prominent points can be seen and the position of these points are known, or have been determined by intersection, then the position of any location of the instrument can be determined by resection. Resection enables a reconnaissance officer to determine the position of any point from which three known points are visible without actually traveling from point to point and without the expenditure of time necessary to travel from one point to another. In rough terrain the use of resection is invaluable.

## 125. Procedure

Since resection requires fewer men, less time, and is usable in many different locations over an area, the reconnaissance officer should try to use this method wherever possible. Traverse is then used to establish a base line, so that intersection can be used to establish known points for use by resection methods. Traverse may then be used to determine position of local points around the known points already established. The interrelation of the three methods allows one method to be used to lead to a faster and better method.

# CHAPTER 9

# VERTICAL CONTROL

## Section I. GENERAL

### 126. General

The principles governing linear measurements have been discussed with particular reference to horizontal distance. In certain instances, mainly when given a field artillery mission, the antiaircraft artillery officer is concerned with the difference in altitude between his battery and the target and between the different guns in the battery. It is important that the reconnaissance officer understand the principles of determining vertical distances and altitudes.

### 127. Definitions

*a*. LEVELING. In this discussion leveling is defined as the determination of difference in altitude between given points or stations.

*b*. DATUM PLANE. An imaginary level surface, all points of which are assumed to have an elevation of zero, and to which all elevations in a given survey are referred. Mean sea level affords the most convenient datum plane, although an arbitrary datum plane may be assumed. The distinction between a *horizontal surface and a level surface* must be kept in mind. It is readily seen that, due to the curvature of the earth, the *level surface* of the mean sea level is in reality a *curved surface*. *Datum level* and *datum plane* are synonymous terms.

*c*. ELEVATION OR ALTITUDE. The distance of a given point or station above or below the datum plane. The term "elevation" is used exclusively in this discussion.

*d*. PLANE OF SIGHT. The line of sight of a telescope instrument used as a level always lies in a horizontal plane of sight no matter in what direction the telescope may be pointed, provided the instrument is in adjustment and properly leveled.

*e*. BENCH MARK (BM). A fixed point of reference whose elevation with respect to some assumed datum plane is known. It is used either as a starting or closing point for leveling.

*f*. STATIONS (STA.). Points whose elevations are to be ascertained or points that are to be established at a given elevation. It is where

the level rod is held and not where the instrument is set up as is the case in a transit traverse.

*g.* HEIGHT OF INSTRUMENT (H.I.). The elevation of the plane of sight with respect to the assumed datum.

*h.* BACKSIGHT (B.S. OR + SIGHT). A sight taken on a rod held at a point of known elevation to determine the H.I.

*i.* FORESIGHT (F.S. OR —SIGHT). A sight taken on a rod held at a point whose elevation it is desired to ascertain.

*j.* TURNING POINT (T.P.). A more or less temporary point, the elevation of which has been determined, used to hold the elevation while the instrument is being moved from one set-up to another.

## Section II. MAP LEVELING

### 128. Use

One of the first things a reconnaissance officer must do when he occupies a position to be used for a field artillery mission is to determine the elevation of the directing gun. As a general rule, this is taken directly from the battle map. The battle map is constructed with great care and shows by means of contours the elevations of all points on the terrain. The position of the station whose elevation is desired is plotted on the map. It is then possible by reading the elevation of the nearest contour line to determine the elevation of the station within one contour interval. By interpolating between bracketing contour lines, the elevation may be more accurately obtained. In determining elevations in this manner, the limits of accuracy of the map must be borne in mind. If the contour lines are close together, indicating steep slopes, it is obvious that a slight error in plotting the position of the station on the map may result in an error in reading its elevation from the map. However, the errors inherent in printing contours on a map may cause an appreciable error in their use in this connection.

### 129. Accuracy

The usual contour interval employed on the battle map is 20 feet. The elevation of the directing point should be known to within 10 feet. It is therefore obvious that the artillery officer must exercise due judgment in reading an elevation from the map. If there is likelihood that map leveling may give errors in elevation which are inadmissible in the firing data, it is necessary to use a more accurate method.

## Section III. TRIGONOMETRIC LEVELING

### 130. Method

Trigonometric leveling consists in the determination of the difference in elevation between two points by means of the angle measured at one of them between the horizontal (or level) line and the other point. This method is of frequent application in the topographical operations pertaining to the artillery. The shorter the sights, the more accurate are the results obtained.

### 131. Stadia

*a.* In the discussion of stadia measurements it was shown that the vertical distance from the instrument to the point sighted on can be obtained if the rod intercept and the vertical angle to the point are known. The vertical distance is computed by means of tables. (See table VI, TM 5–236.)

*b.* It is necessary to take into consideration the height of the instrument above the ground when the elevation of an object on the ground is to be determined. If the object is situated at about the same distance above the ground as the instrument, this correction need not be made. For long distances it is necessary to make certain corrections for atmospheric refraction and for curvature of the earth.

### 132. Method

*a.* When the elevation $H$ of the ground at the station $A$ is known and the elevation $H'$ of the sighted point is known, let $\alpha$ = the slope measured, positive for an ascending slope and negative for a descending slope.

$D$ = the horizontal distance $AB$,
$h$ = the height of instrument at $A$ above the ground, and
$h'$ = the height of the sighted point $B$ above the ground.

Then the formula becomes, with due regard for the sign $\alpha$

$$H' = H' + D \tan \alpha + (h - h')$$

The quantity $(h - h')$ becomes zero if the sighted point is exactly the same height above the ground as the sighting instrument.

*b.* When the altitude $H'$ of the sighted point is known, and the elevation $H$ of the ground at the station is unknown, the elevation of the instrument station is found by using the same formula with the signs changed. Thus,

$$H = H' - D \tan \alpha - (h - h')$$

### 133. Example

*a.* Assume that it is desired to obtain the elevation of a distant sta-

tion, $B$, from station $A$. Elevation of $A$ is given as 693.7 feet and from the coordinates of the stations the distance, $AB$, has been computed to be 6,795 feet. The instrument is set up at $A$ and because of trees station $B$ cannot be seen; however the lower limb of a tree alongside it is visible. This is measured and is 9.9 feet above $B$. By sighting on the lower limb of this tree the vertical angle is found to be 4° 36′. The telescope is 5.2 feet above $A$.

*b*. Our computations are then as follows:

$D \tan \alpha$

$$\begin{aligned} \log 6795 &= 3.83219 \\ + \log \tan 4^\circ\ 36' &= 8.90557 \\ \hline \log D \tan \alpha &= 2.73776 \\ D \tan \alpha &= 546.7 = T \end{aligned}$$

$(h - h')$

$$\begin{aligned} h &= 5.2 \text{ feet} \\ h' &= 9.9 \text{ feet} \\ h - h' &= 4.7 \text{ feet} \end{aligned}$$

Substituting in the formula, we have:

$H = 693.7 + 546.7 - 4.7 = 1235.7$ feet = Altitude of "$B$".

## Section IV. SPIRIT LEVELING

### 134. Instruments

*a*. Spirit leveling is so called because it makes use of a spirit level attached to a telescope, or other device for defining a line of sight, to make the line of sight level. The term "Differential Leveling" is applied to the operation of obtaining the difference in elevation between two stations by means of a spirit level.

*b*. The instruments in general use for spirit leveling are:

(1) The engineer's complete transit or theodolite.

(2) The Wye Level.

(3) The Dumpy Level.

(4) The Hand Level.

*c*. Since the engineer's complete transit is the instrument almost exclusively used by the reconnaissance officer in the field work connected with his problems, the discussion applies to it alone, although the theory of spirit leveling applies equally well to the other instruments mentioned.

### 135. Theory

*a*. There are two steps in leveling for any single set-up:

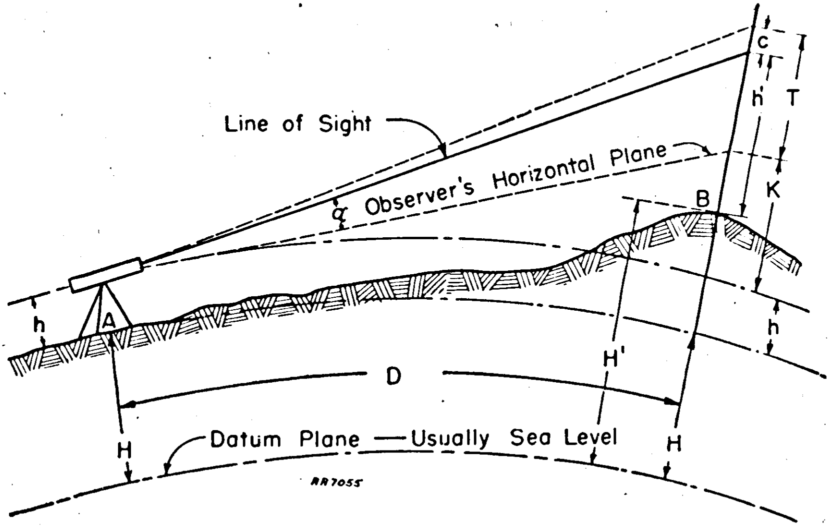



*Figure 75. Trigonometric leveling.*

(1) To find how far the plane of sight is above a point of known altitude. This is the backsight rod reading.

(2) To find how far a given station is *below* the plane of sight. This is the foresight reading.

*b.* The repeated applications of these two steps constitute a "level circuit," or "line of levels."

*c.* Consider the case shown in figure 76.

(1) The instrument is set up and carefully leveled as has been previously described. Care must be taken to see that the line of sight, when level, strikes on the rod held on the B.M. In case of doubt this is verified by directing the telescope toward the B.M. and centering the telescope bubble before centering the plate bubbles. A sight through the telescope then indicates whether the instrument is too high or too low.

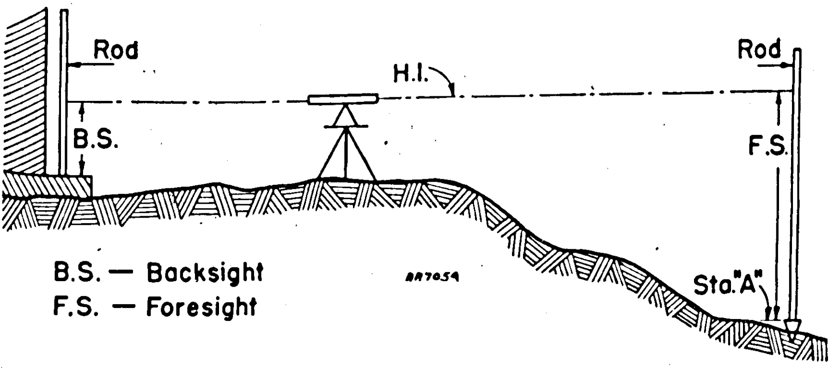



*Figure 76. Spirit leveling.*

This simple precaution frequently saves much time and annoyance.

(2) Sight on the level rod held on the B.M. Carefully center the telescope bubble and read the rod.

(3) Verify the centering of the bubble. If it has moved, repeat the reading of the rod.

(4) Record the rod reading and compute the H.I. The rodman now goes ahead to the next point, either a station or a T.P. If it is a T.P., he must be directed where to set it so that the instrument man can read the rod.

(5) Proceed as before with the telescope sighted on the rod as the forward point.

(6) Record the rod reading and compute the elevation. This completes the two steps. The level circuit is continued by a repetition of the foregoing.

*d.* It is not necessary to have the elevation of the starting point referred to sea level datum plane unless the elevation of the station is desired with respect to the same datum plane. For the purpose of obtaining difference in elevation only, any datum plane may be assumed for the starting point.

## 136. Notes

*a.* In order to avoid confusion, it is necessary to adopt some suitable system of recording the notes. The system may vary for different cases but a satisfactory method is shown below, which represents the field notes on the level circuit shown in figure 77.

*b.* These notes show the method of recording a rod reading on an intermediate station as "*A*". In some level circuits, as for profile leveling or cross sectioning, the intermediate readings may be more numerous than the readings on B.M.s or T.P.s. But ordinarily in differential leveling there are very few intermediate readings and these are taken to establish altitudes for possible future reference. Such intermediate stations, if they are permanent, then become B.Ms. It is a good plan to draw a ring around the most important elevations for convenience in picking them out and to distingush them from elevation of T.Ps. All bench marks and important stations must be so carefully described that they can be found at any time without difficulty. This is an important point, frequently neglected.

## 137. Level rods

*a.* There are two types of leveling rods:

(1) Target rods, having a sliding target which is set by the rodman on signals from the levelman.

(2) Self-reading or direct reading rods, read directly by the levelman.

*b.* The self-reading rod is probably the most popular. However, the target rod presents less chance for mistakes and in a circuit of very

accurate levels the target is always used. Most direct reading rods are also provided with a target.

## 138. Error of closure

As in the case of a transit traverse a circuit or running of levels must always be checked either on the starting point or on some other point whose altitude is known. Errors are to be expected. The error of closure of a level circuit run with a transit in good adjustment, with careful methods and sights ranging about 200 feet should not exceed $E = .002\ S$, where $E$ = error of closure in feet, $S$ = number of instrument set-ups.

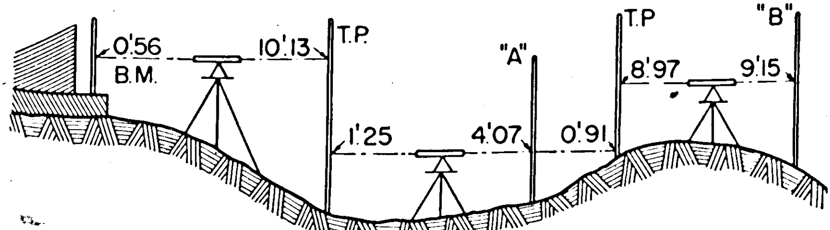
## 139. Errors

*a.* Instrumental errors. These are practically confined to errors of adjustments. They may be entirely eliminated by making the lengths of backsights and foresights equal.

*b.* Mistakes in manipulation. (1) The bubble may be incorrectly centered.

(2) If the observer rests his hands on the tripod he may cause an error.

(3) The leveling rod must be held plumb or perpendicular to the




| Left Hand Page | | | | | Right Hand Page |
|---|---|---|---|---|---|
| Levels to Obtain Altitude of | | | | | Station B — May 9 1942, Capt. Roe, Lieut. Doe |
| Sta. | B.S. | H.I. | F.S. | Elev. | Remarks |
| B.M. | 0.56 | 179.69 | | 179.13 | Here give complete description of B.M. giving Authority for its Elevation. |
| T.P. | | | 10.13 | 169.56 | |
| ⊼ | 1.25 | 170.81 | | | |
| "A" | | | 4.07 | 166.74 | Describe |
| T.P. | | | 0.91 | 169.90 | |
| ⊼ | 8.97 | 178.87 | | | |
| "B" | | | 9.15 | 169.72 | Describe |

*Figure 77. Diagram of line of levels extract from field notebook.*

line of sight. When "short rod" is used, the rodman can easily balance the rod on the station and hold it steady. When "long rod" is used, or for readings over 6 feet it is usually advisable to "wave the rod." The rodman stands directly behind the rod, facing the instrument he leans the rod, first toward the instrument, then away from it, top describing an arc about 0.15 foot long. The instrument man selects the lowest reading on the rod.

(4) Dirt or any accumulation, as of snow or ice on the foot of the rod, introduces an error.

*c.* Mistakes in reading leveling rod. Misreading 8 for a 9 or vice versa, transposing figures, are among the common mistakes. Each observer must learn his own peculiarities in this respect.

*d.* Errors in sighting. Coarseness of the crosswire, graduations of the rod or form of the target and the eyesight of the levelman all have to do with such an error. In using the transit as a level instrument it is a common mistake to use one of the stadia wires for horizontal wire. Long sights must be avoided. 250 feet is long enough with the average instrument when leveling with a spirit level and reading hundredths of feet.

*e.* Errors due to change in position of instrument or rod. These may be avoided by setting up on firm ground and taking the foresight immediately after taking the backsight. Small wooden stakes driven diagonally into the ground and using the high corner make satisfactory turning points. Loose stones must not be used. Turning points are carefully selected with regard to the next setup. Be careful in walking around the instrument not to jar or disturb it.

*f.* Errors due to natural sources. Unequal expansion of different parts of the instrument, change of length of level rod, curvature of the earth, and refraction of the atmosphere are included under this head. They are usually inappreciable and are ignored in ordinary work, but are taken into account in precise leveling.

see c1

~~*g.* Mistakes in recording and computing. Transposing figures, re-~~cording foresight as backsight or omitting a force or ~~backsight~~ sight entirely are among the common mistakes. A ~~convenient~~ check on the computations is obtained by the ~~following~~ rule: add all backsights together; add all turning point ~~foresights~~, including the foresights on the closing point, ~~together;~~ the difference between these guns should equal the dif~~ference between~~ the elevations ~~of the starting and closing~~ stati~~ons.~~

## CHAPTER 10

# ELEMENTARY ASTRONOMY

## Section I. THE CELESTIAL SPHERE

### 140. General

Precise determination of azimuth is dependent upon the relation of some celestial body to an observer on the earth. In order to understand methods of azimuth determination, it is necessary to understand some of the more basic theories of astronomy. The study of astronomy is simplified if apparent motions of celestial bodies are considered rather than true motions. For example, it is known that the earth revolves around the sun; however, to the observer on the earth, the sun *apparently* travels around the earth. As this apparent movement is witnessed daily the student is accustomed to think in terms of the sun moving rather than the earth. The following paragraphs deal primarily with apparent motions of celestial bodies rather than real motions, as direction is the result of apparent motion.

### 141. Celestial sphere

The stars are spaced at varying distances from the earth but the distances are so great that they are all considered infinite. Inasmuch as the distances are all infinite, the stars are assumed to all be located on a sphere of infinite radius with the earth as its center. Since the size of the earth is so small as compared to the distance to the sphere, an observer any place on the earth may be considered as being at the center of the sphere. This sphere is called the "Celestial Sphere."

The observer may visualize this sphere by observing the heavens on a clear night. The stars all appear to be at the same distance, or if, as is the case with some observers, they appear to be at varying distances, no idea can be formed of their relative distances. It is easy to imagine them all to be placed on the inner surface of an immense sphere—the celestial sphere.

### 142. Declination

Coordinates of some kind are needed so that any point on the celestial sphere may be designated accurately in the same manner that points

are designated on the earth by latitude and longitude. The poles of the celestial sphere are at the prolongation of the poles of the earth. The celestial equator is formed by extending the plane containing the earth's equator until it strikes the celestial sphere. The celestial equator is then a line of zero declination in the same way as the earth's equator is a line of zero latitude. Declination on the celestial sphere corresponds to latitude on the terrestrial sphere and is measured in the same way, in degrees, minutes, and seconds of arc from the equator to the poles. However, declination is not considered as being either a north or a south declination as is latitude, but a "north declination" is positive declination and a "south declination" is negative declination, denoted by an algebraic sign preceding the angle in degrees. Thus the declination of the star Sirius would be written as —16° 38.3′, showing that it is in a position, corresponding to a latitude of 16° 38.3′ south on the terrestrial sphere.

### 143. Right ascension

Right ascension on the celestial sphere corresponds to longitude on the terrestrial sphere. Longitude is measured in either an eastward or westward direction from the zero meridian through Greenwich to 180° in either direction. Right ascension, however, is measured from the vernal equinox in an eastward direction only, completely around the sphere. However, instead of being measured in degrees it is measured in hours, minutes and seconds of time from 0 to 24 hours. Thus a star may be designated as having a right ascension of 22 hours, 30 minutes (337° 30′), whereas on the earth, the longitude of a point is never more than 180° from the Greenwich Meridian. Right ascension may be considered as a measure of the time elapsed from the time the vernal equi-

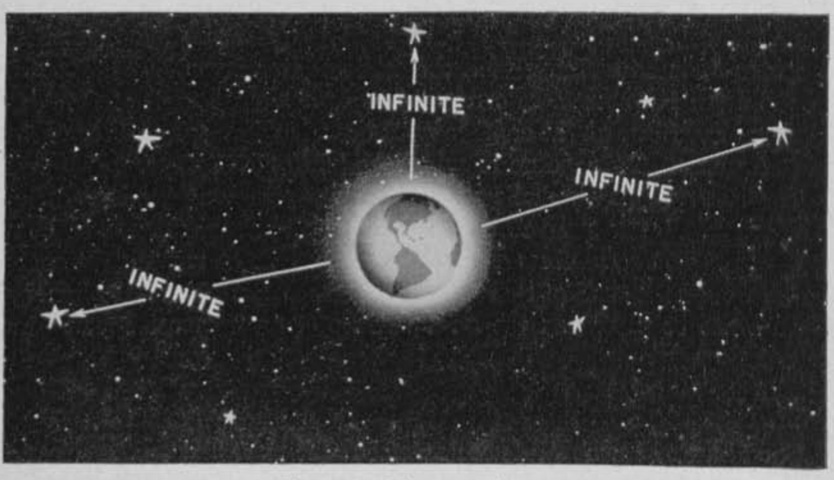



*Figure 78. Distances of stars.*

nox passes over the observer's meridian until the instant a certain star passes over the same meridian. In other words a star having a right ascension of 6 hours, 10 minutes, crosses the observer's meridian 6 hours and 10 minutes after the vernal equinox has crossed the same meridian.

### 144. Vernal equinox

The vernal equinox is a fixed point on the celestial sphere and is the point on the celestial equator at which the sun crosses the celestial equator on March 21st when passing from a minus (southern) declination to a plus (northern) declination. The vernal equinox is indicated on the celestial sphere by a line from the north celestial pole almost passing through the leading star (Beta) of the constellation Cassiopeia. The intersection of this line and the celestial equator is the vernal equinox.

### 145. Movements of celestial sphere

The earth rotates about its axis, making a complete revolution in a period of 24 hours. An observer on the earth is carried along in such a way that the sun and stars appear to pass around the earth. The celestial sphere is apparently revolving around the earth. The movement is such that the stars, sun, and moon rise in the east and set in the west. The celestial sphere is assumed to revolve around the earth, which is considered to be stationary.

### 146. Observer's meridian

The observer's meridian is an imaginary great circle line on the celes-

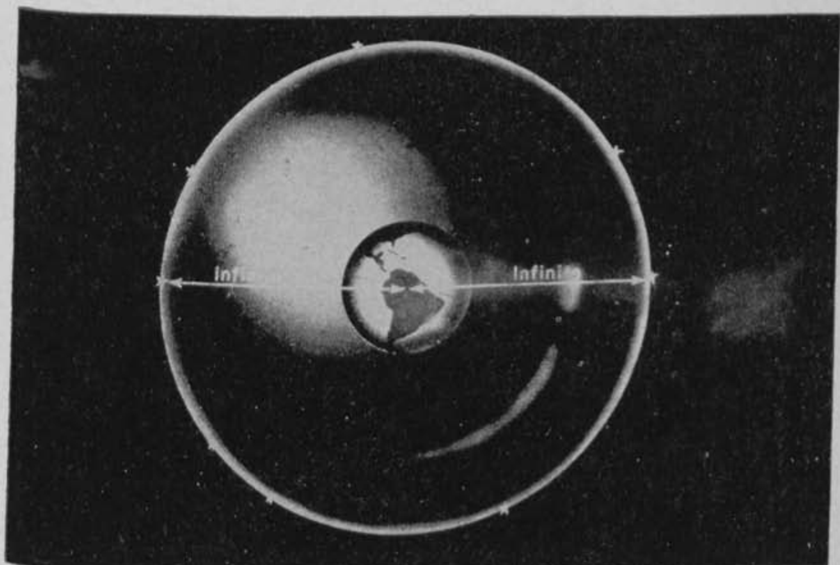


*Figure 79. The celestial sphere.*

tial sphere made by passing a vertical plane through the observer's position and the north and south celestial poles. This line then passes from the north celestial pole directly over the observer's position and on to the south celestial pole. The point directly over the observer's position is known as the *observer's zenith.* This point is a point on the observer's meridian.

## 147. Star identification

*a.* Star identification may be simplified by visualizing an imaginary scale attached to the celestial equator. This scale is divided into 24 hour units progressing from 0 to 24 hours in an eastward direction. The zero is placed at the vernal equinox. A star having a right ascension (longitude along the celestial equator) of 12 hours is then somewhere along an hour circle line passing through the north and south celestial pole and the 12-hour mark on the imaginary scale.

*b.* As the night progresses, the imaginary scale revolves from east to west, and stars each having a greater right ascension continue to rise above the eastern horizon. By using the line from the north celestial pole through Beta of Cassiopeia shown in figure 84 as an indicator of zero right ascension (this line or hour circle passes through the vernal equinox) the approximate right ascension of a star overhead may be

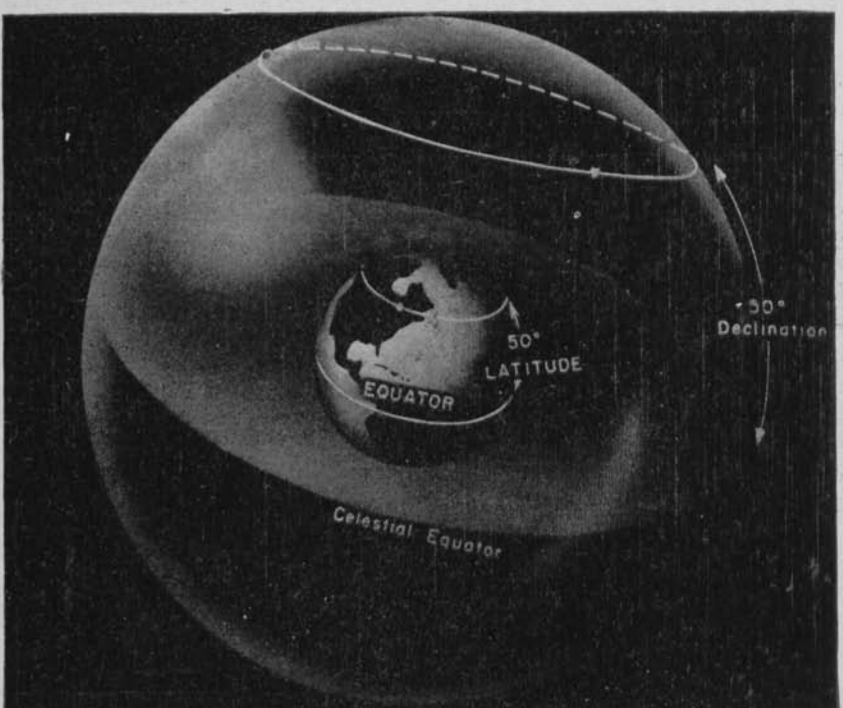



*Figure 80. Measurement of declination on the celestial sphere.*

estimated by judging the angle through which the line has passed since being overhead. An angle of 45° will be one-eighth of a complete circle or one-eighth of 24 hours or 3 hours. So that if the zero hour circle has moved past the observer's meridian by 45°, a star directly overhead will have a right ascension of 3 hours. Or, the sidereal time (star time) is thus 3 hours, as sidereal time is the same as the right ascension of the observer's meridian at that particular instant. The star is located now in an east and west direction but its position along this particular hour circle in a north and south direction is unknown. This position may be determined by declination of the star. A star whose declination is +45° will be located half way between the north celestial pole and the celestial equator so if the star Polaris which is very close to the north celestial pole can be seen, an angle of 45° may be estimated along the hour circle of the star toward the south. The declination of the observer's zenith is always the same as his latitude so that a point overhead (the zenith) of an observer at latitude 30° north will be +30°. An observer's zenith for an observer at the equator will have a declination of 0°. This then gives an observer an additional guide as to the declination of certain points in the sky. By the use of this method, any first magnitude star may be identified if the right ascension and declination of the star are known. A practical example will illustrate the method of identification. Assume the star Deneb is to be located. Deneb has a right ascension of 20 hours 39.5 minutes which is nearly 21/24 of a complete circle or 315° of angle. The angle of Deneb from

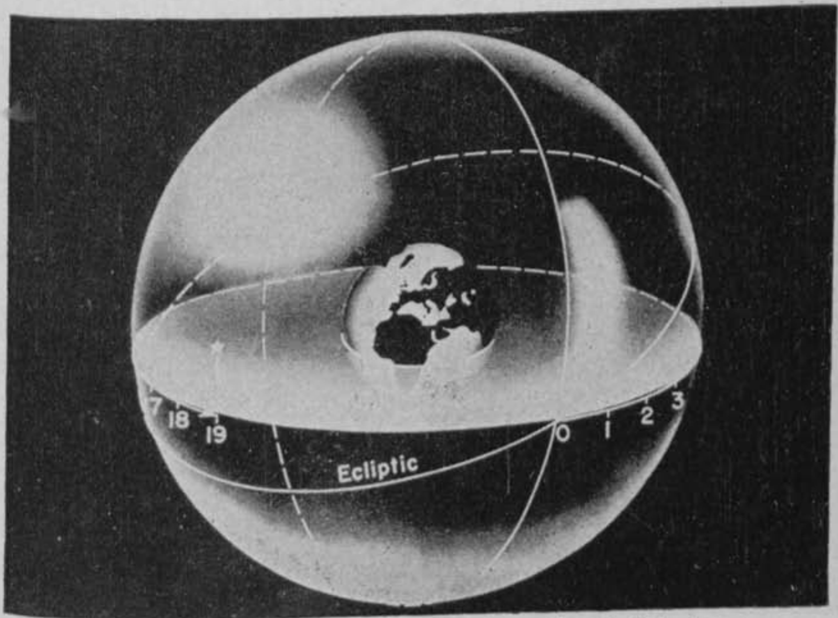



*Figure 81. Measurement of right ascension on the celestial sphere.*

0° or the line through the vernal equinox is then 315°. The zero line or zero hour circle is located by imagining a line drawn from the north celestial pole almost through Beta of Cassiopeia as shown in figure 86.

*c.* After locating this zero hour circle, estimate an angle of 315° measured in a clockwise direction (opposite to direction of rotation of the celestial sphere) as shown in figure 87. The star Deneb will be somewhere along the hour circle from the north celestial pole through the 315° angle point.

*d.* The declination of Deneb is +45° 05.0′ or very near 45/90 of the arc, from the north celestial pole to the equator. The 45° distance along the 315° hour circle will identify the position of Deneb as Deneb is the only bright star in the vicinity. (See fig. 88.)

*e.* A more complete method of star identification is presented in chapter 14.

## 148. Sidereal time

Sidereal time or star time is the star time at an observer's position or the star time for some chosen position. Every point on an east-west line on the earth has a different sidereal time as an observer in one point does not see the stars in the same degree of revolution as an observer either east or west of his position. Therefore, the sidereal time for a given position is the sidereal time indicated by the hour circle passing through the zenith of that position. Using the same imaginary scale, attached to the celestial equator, as was assumed in paragraph 147,

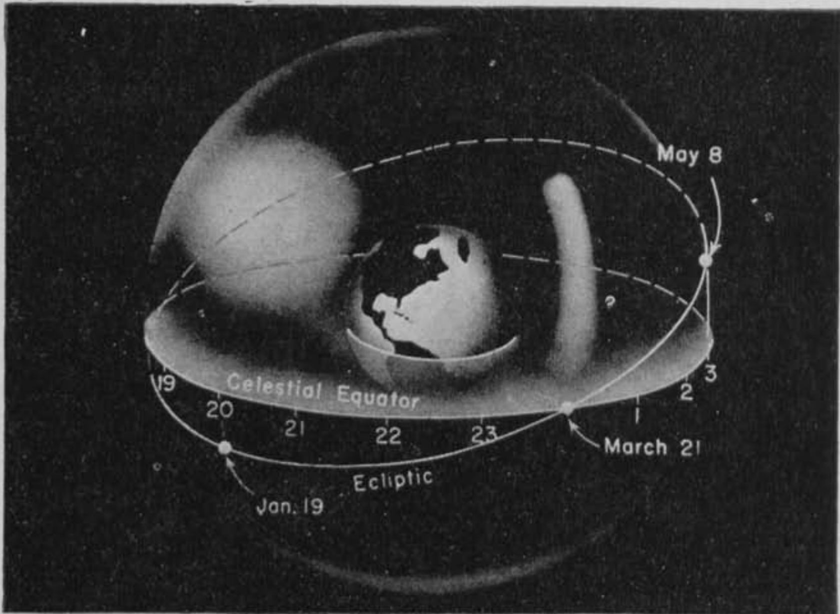



*Figure 82. Course of sun around celestial sphere throughout the year.*

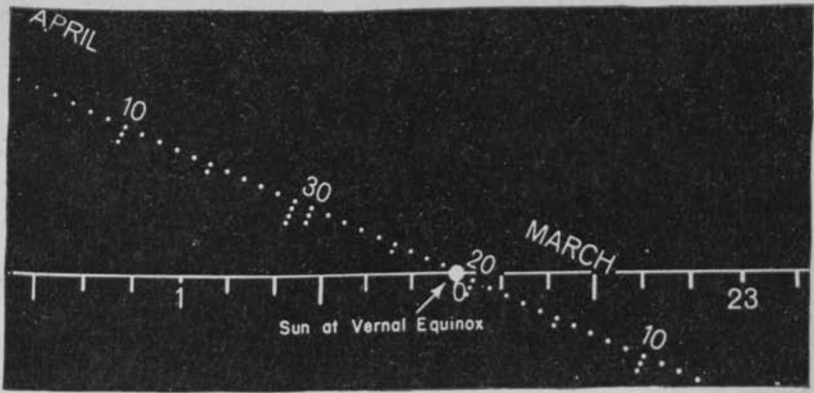



*Figure 83. Vernal equinox as view from the earth.*

visualize this scale as moving with the celestial sphere. The zero of this scale is at the vernal equinox (zero right ascension point). Now we will fasten a fixed scale on the outside of the celestial sphere so that the zero of this fixed scale will be on the observer's meridian as shown in figure 89. Now as the celestial sphere rotates, the movable scale will move with it from east to west but the fixed scale will remain stationary with its zero on the observer's meridian. The fixed scale is also divided into 24-hour divisions but in the opposite direction. As the movable scale progresses with the celestial sphere the sidereal time will constantly be indicated at the zero of the fixed scale as shown in figure 90. In

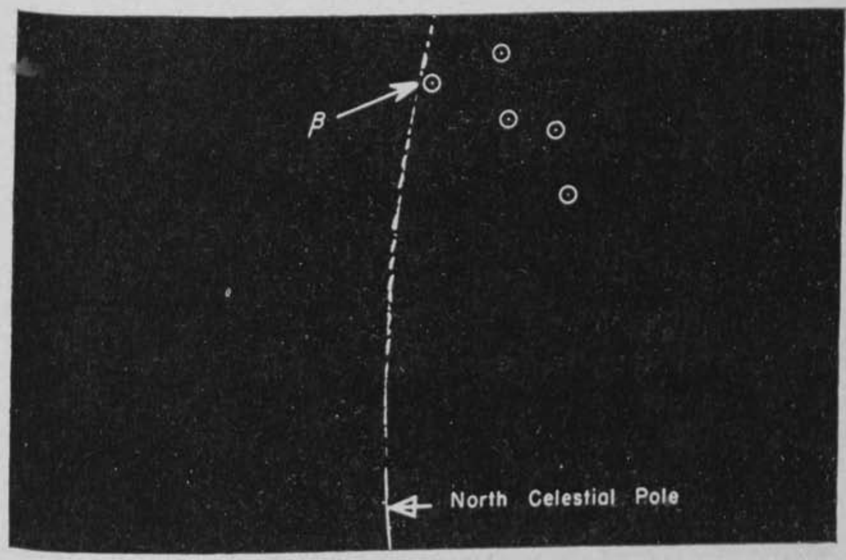



*Figure 84. Line pointing to the vernal equinox.*

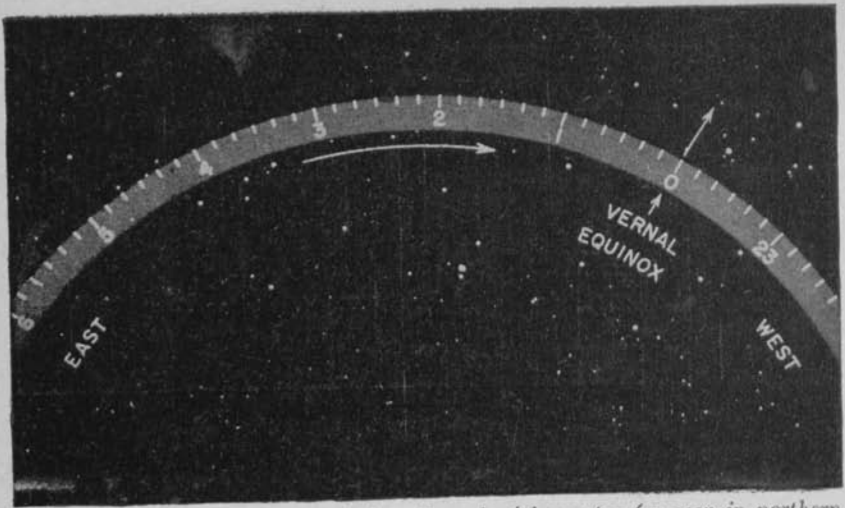


*Figure 85. Imaginary scale attached to the celestial equator (as seen in northern hemisphere, observer facing south).*

other words the sidereal time on the observer's meridian is the same numerically as the right ascension of a star on the observer's meridian.

## 149. Hour angle

The hour angle of a star is a requisite for the solution of observation for azimuth determination. Hour angle is merely the amount of rotation that has taken place by a star, since it last passed a given meridian.

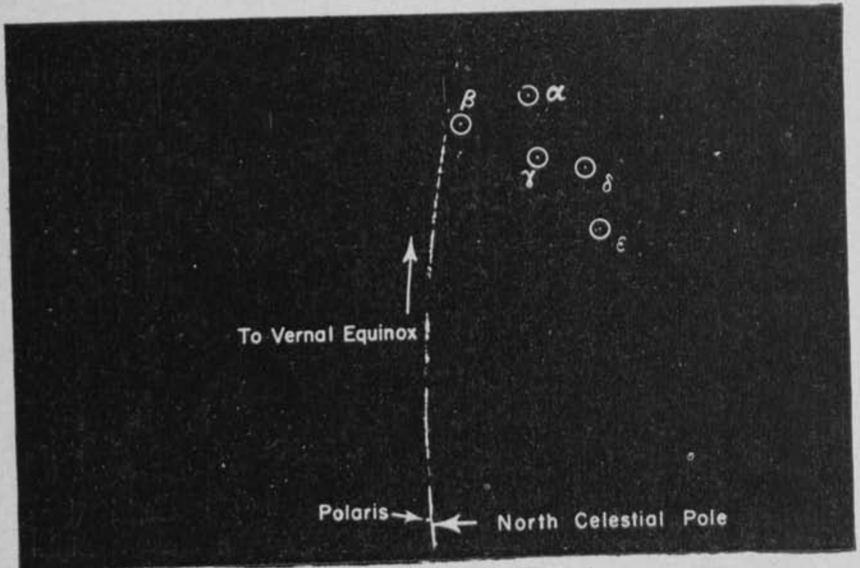


*Figure 86. Line of zero right ascension.*

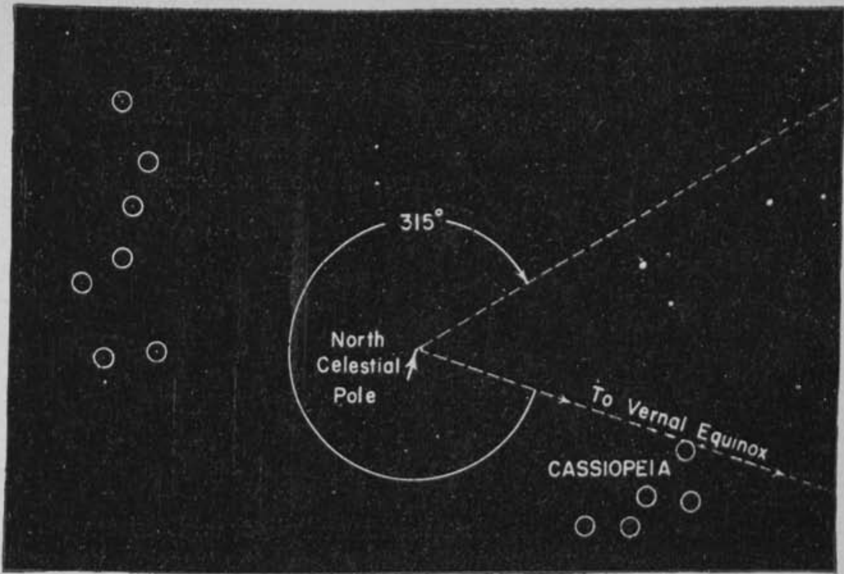



*Figure 87. 315° angle from zero hour angle.*

For example, in figure 91, the hour angle of the vernal equinox is indicated by the position of the zero of the movable scale as 21 hours and 50 minutes. In other words it has been 21 hours and 50 minutes since the vernal equinox has passed the observer's meridian. For convenience hour angles are usually reckoned in less than 12 hour angles. To do this the hour angle shown in figure 91 would be considered as $21^{hr}$ $50^{min}$ $-24^{hr}$ or a $-2^{hr}$ $10^{min}$ hour angle. The use of negative hour angles when the hour angle is more than $12^{hr}$ (180°) facilitates compu-

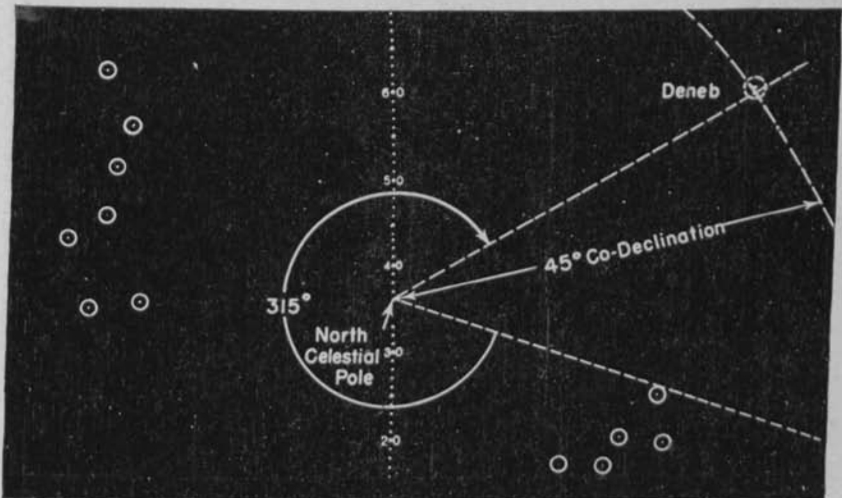



*Figure 88. Identification of star Deneb.*

tations for azimuth determination. Figure 92 is a picture made in a planetarium of the star Sirius whose right ascension is $6^{hr}$ $42.6^{min}$ and in a position $0^{hr}$ $36^{min}$ past the observer's meridian. The hour angle of the star Sirius in this case is $+0^{hr}$ $36^{min}$. Note that the star Sirius continues to have a right ascension of $6^{hr}$ $42.6^{min}$ throughout the day (the star moves with the movable scale) but the hour angle changes continuously.

## Section II. THE SUN

### 150. Movement

The earth moves around the sun in an elliptical orbit over a period of one year as shown in figure 93. Throughout the travel of the earth around this orbit the axis of the earth remains inclined at an angle of about 23½° to the vertical axis of the earth's orbit around the sun as shown in figure 94. The inclination of the earth's axis causes more direct rays of the sun to be projected on the northern hemisphere in the summer and the southern hemisphere in the winter, thereby causing the seasons of the year. To an observer on the earth, however, the sun appears to move from an extreme northern declination in the summer to an extreme southern declination in the winter as shown in figure 95.

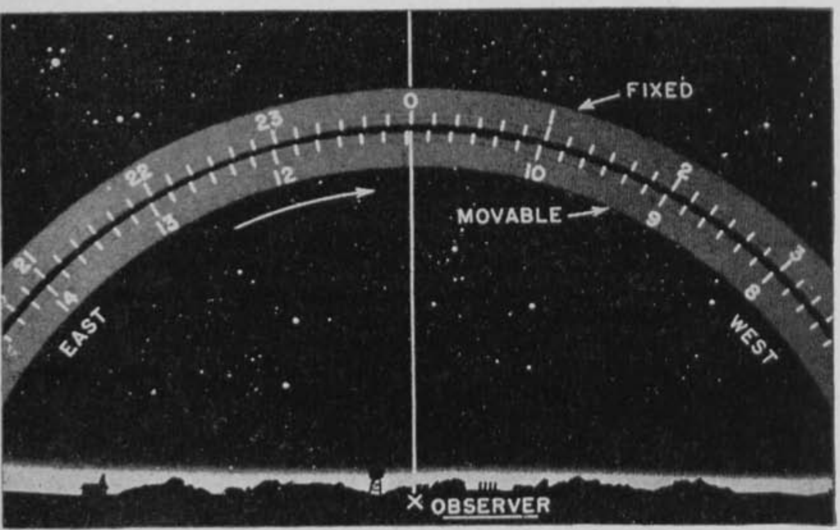



*Figure 89. Imaginary scales on celestial equator (as seen in Northern Hemisphere, observer facing south).*

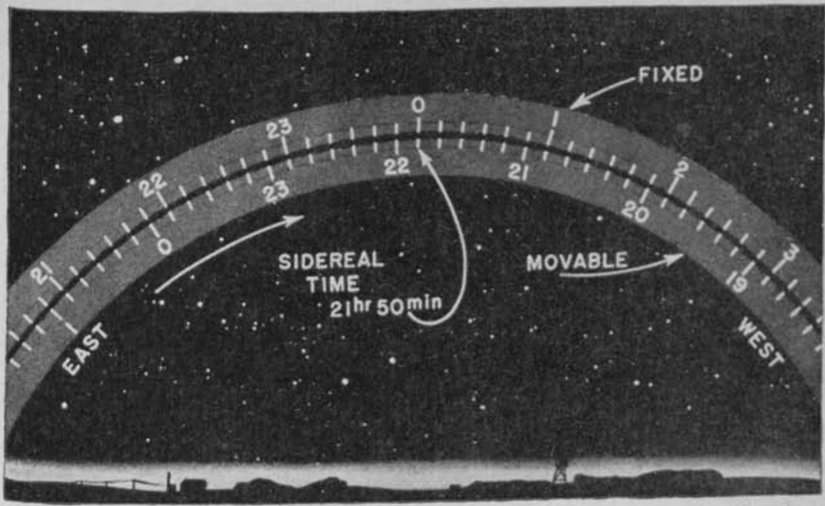



*Figure 90. Sidereal time indicated on observer's meridian (as seen in Northern Hemisphere, observer facing south).*

To the observer on the earth the sun appears to be placed on the celestial sphere but unlike a star it does not remain in a fixed position on the sphere. Due to its change in declination, it moves above and below the celestial equator and due to the difference between star (sidereal) time and solar time, the sun appears to recede around the celestial sphere in an east and west direction so that it appears to travel through certain constellations on the celestial sphere. Figure 96 taken in a plane-

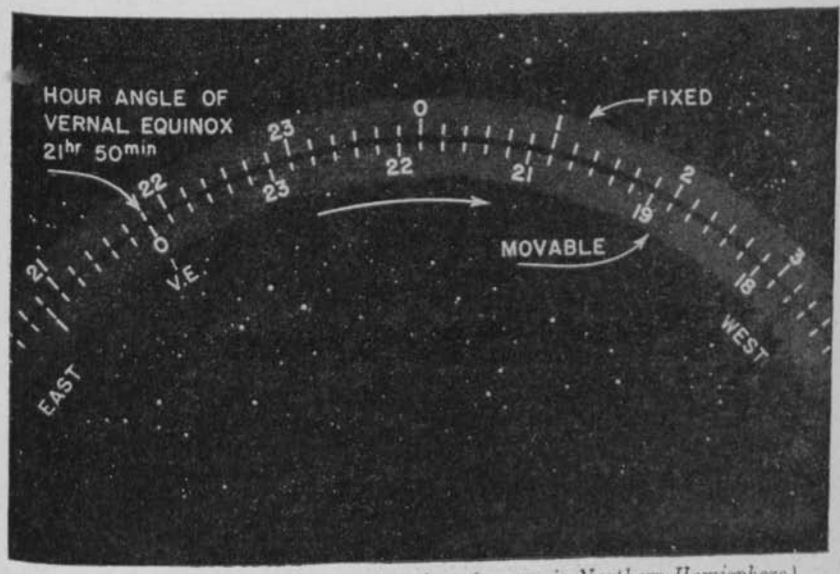



*Figure 91. Hour angle of the vernal equinox (as seen in Northern Hemisphere).*

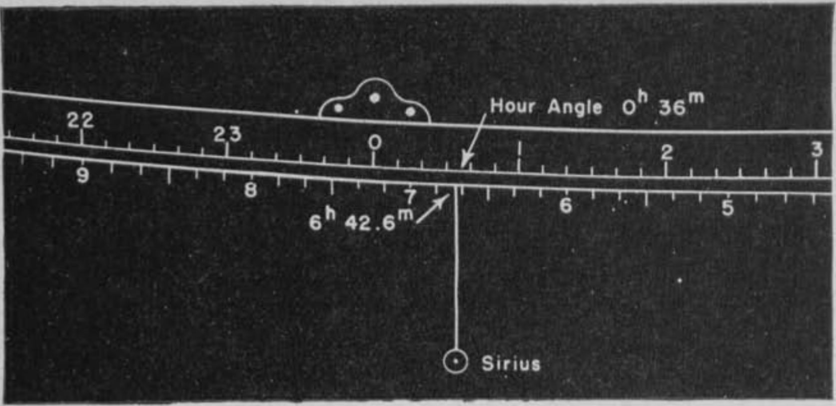



*Figure 92. Sirius at an hour angle of $0^{hr}\ 36^{min}$.*

tarium shows the position of the sun on June 22nd and the position it would have on the celestial sphere for other dates near that time.

## 151. Ecliptic

The course of the sun around the celestial sphere is called the *ecliptic*. The point where the ecliptic crosses the celestial equator is called the *equinox*. The vernal equinox is the point where the ecliptic crosses the celestial equator when the sun is passing from a minus declination to a plus declination. In other words, when the sun is passing from the south to the north (fig. 97).

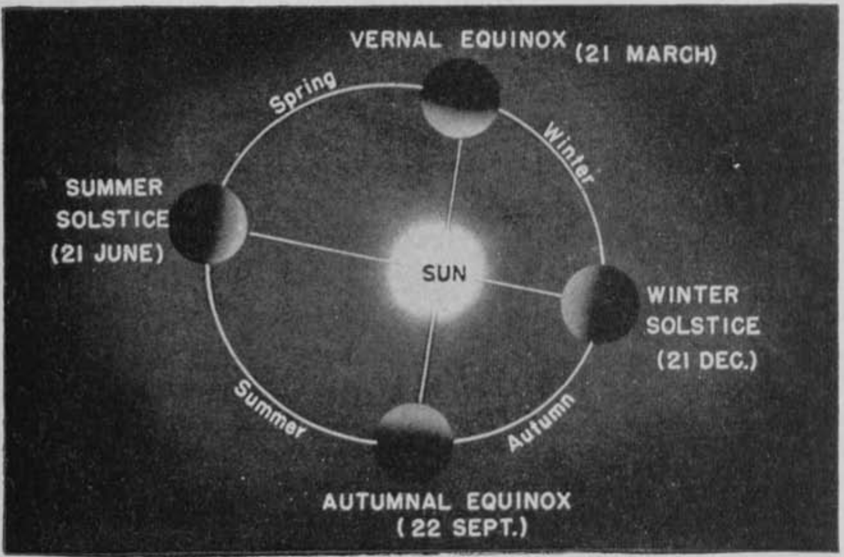



*Figure 93. Orbit of earth around sun.*

## 152. Relation to celestial sphere

The sun revolves around the earth with the celestial sphere except that it drops behind in the degree of rotation gradually so that in one year the sun has made one less turn about the earth than has the celestial sphere. This causes the sun to appear to be among the stars of different constellations as the year progresses. These constellations are the ones in the vicinity of the ecliptic and are known as the constellations of the Zodiac. The reason for the movement of the sun on the celestial sphere is explained in the following section.

# Section III. TIME

## 153. General

There are two general classes of time: sidereal or star time, and solar or sun time. These two kinds of time are the basis for all other kinds of time such as apparent time, civil time, or mean time. The average person does not use sidereal time but his activities are regulated by some form of solar time.

## 154. Solar time

Solar time is based on the solar day or the time between successive *lower* transits of the meridian by the sun. If an observer sees the sun directly overhead or on his meridian the time for his position will be noon or 1200. If his meridian is continued on around the other side of the earth, it will then be 12 hours until the sun crosses the lower part of his meridian (makes a *lower* transit) and at the time of crossing this lower meridian, the time for the observer will be 2400. This time will then be the beginning of the next solar day for the observer. See figure

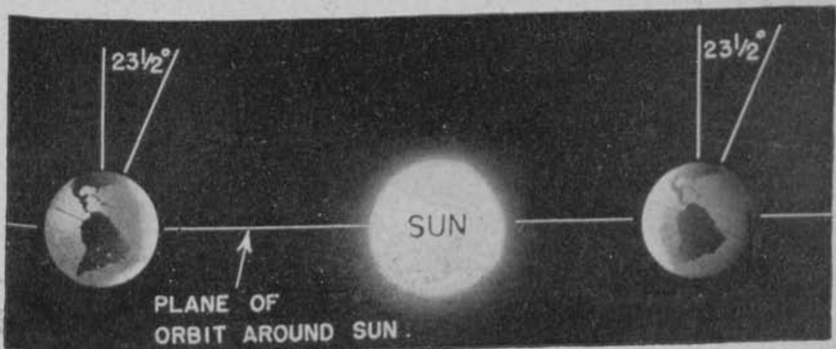



*Figure 94. Inclination of earth's axis.*

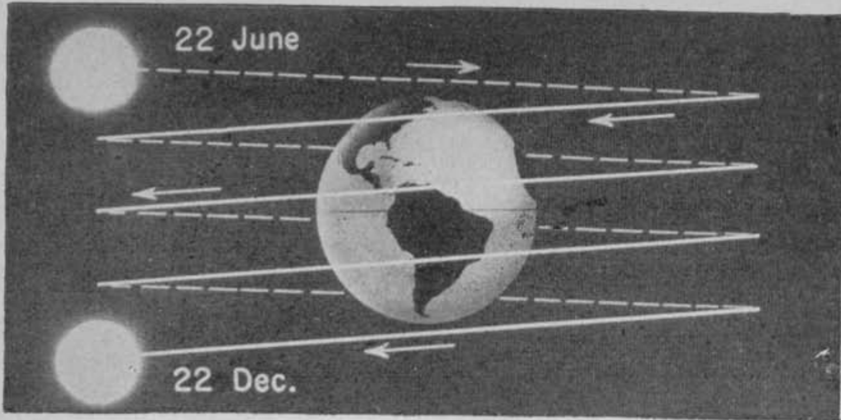


*Figure 95. Apparent movement of the sun.*

98. The observer in this case is on the side of the earth at which the time is midnight.

## 155. Sidereal time

Sidereal time is a measure of the angle through which the earth has rotated since the vernal equinox was on the observer's meridian (made an *upper* transit), or as we see it from the earth, the measure of the angle through which the celestial sphere has rotated since the vernal equinox was on the observer's meridian. (See fig. 99.)

## 156. Comparison of sidereal time and solar time

A solar day is longer than a sidereal day because the earth must re-

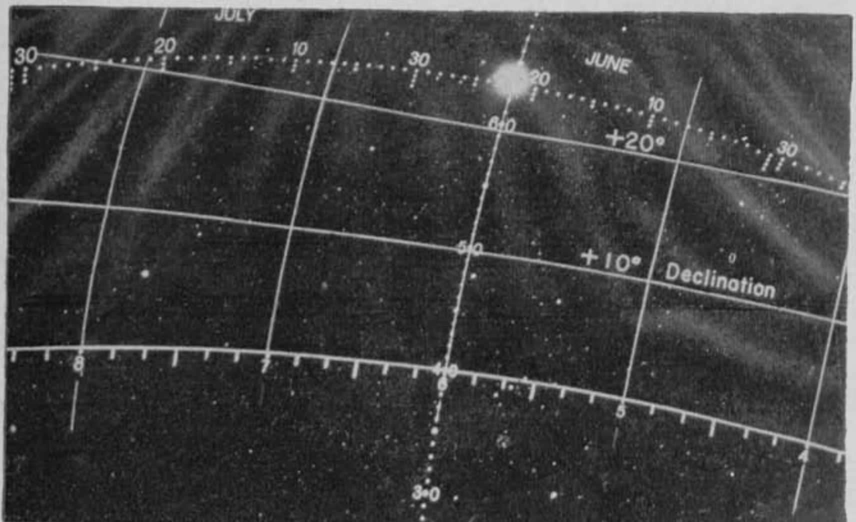


*Figure 96. Sun's position on 22 June.*

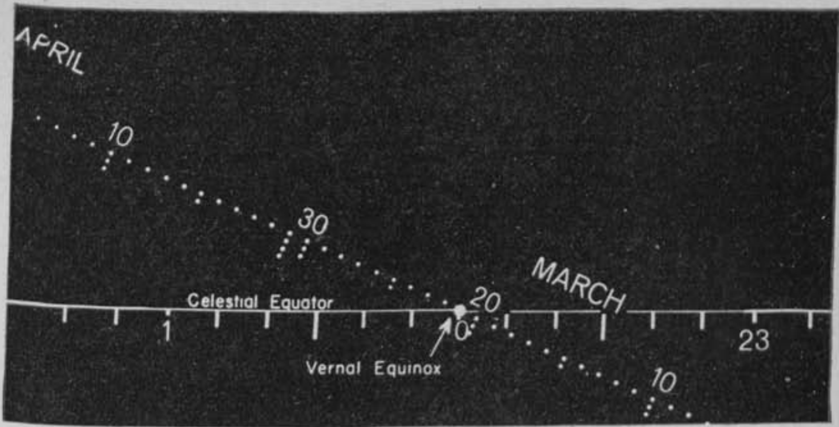



*Figure 97. Sun at vernal equinox.*

volve farther to cause a transit of the sun on successive days. (See fig. 100.) The period of time required for the earth to make one complete revolution around the sun is known as a *tropical year.* (See fig.


*Figure 98. Sun at lower transit of observer's meridian.*

101.) The tropical year contains 365.2422 mean solar days. In the course of one tropical year the sun makes one less transit across the observer's meridian than does a fixed star (or the vernal equinox) because the earth revolves around the sun but does not revolve around the star. (See fig. 102.) The tropical year therefore contains 366.2422 sidereal days and only 365.2422 solar days. Sidereal time is based on an *upper* transit of the vernal equinox over a meridian while solar time is based on a *lower* transit of a meridian. When the sun is at the vernal equinox, the solar time and the sidereal time will vary by 12 hours and will vary from 0 to 24 hours in the course of the year. The amount of variance is proportional to the number of days since the sun was at the vernal equinox. This variance in time is the result of the apparent travel of the sun around the celestial sphere.

## 157. Apparent time

*a.* The solar day begins at midnight, the instant of lower transit of the sun. (See fig. 98.) Apparent time is regulated by the movement of the sun and is the time as shown by a sundial. However, because the earth revolves around the sun in an elliptical orbit, the apparent angular motion of the sun is not uniform. For information, rather then because the data are necessary to the practice of celestial observation, it might

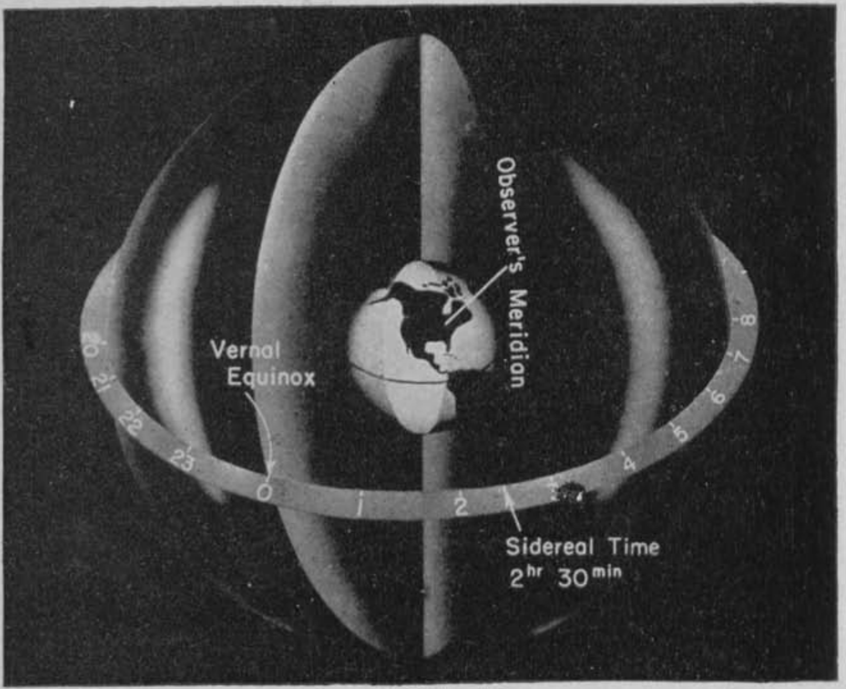



*Figure 99. Sidereal time.*

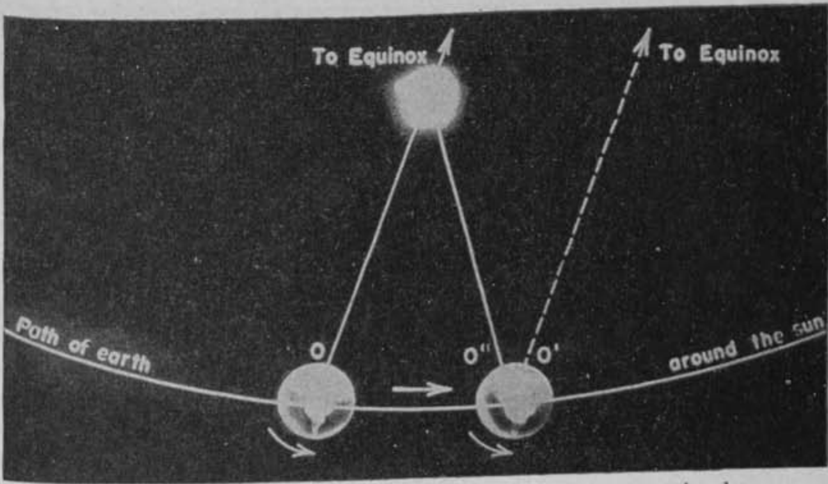


*Figure 100. Comparison of transit of sun and equinox on successive days.*

be stated that the motion of the earth is in accordance with the following laws known as Kepler's Laws:

(1) The orbit of the earth (and other planets) is an ellipse, having the sun at one of its foci.

(2) The radius vector of a planet sweeps over equal areas in equal times.

(3) The square of the times of revolution about the sun of any two planets are proportional to the cubes of their mean distances from the sun.

*b.* The length of the solar day is therefore not the same throughout the year. (See fig. 103.)

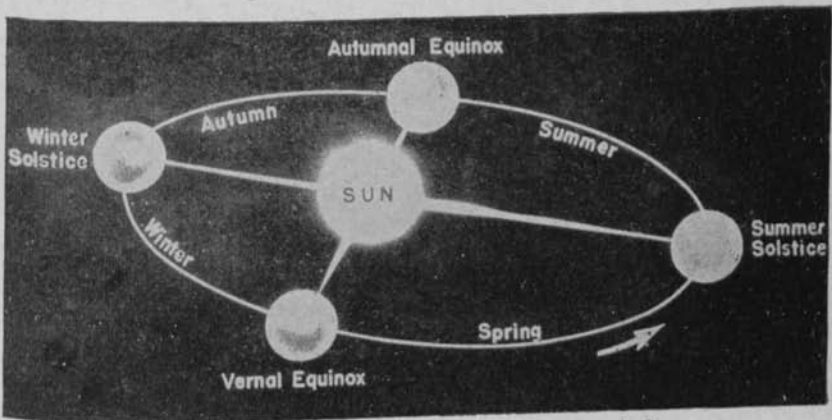


*Figure 101. Course of earth around sun in one tropical year.*

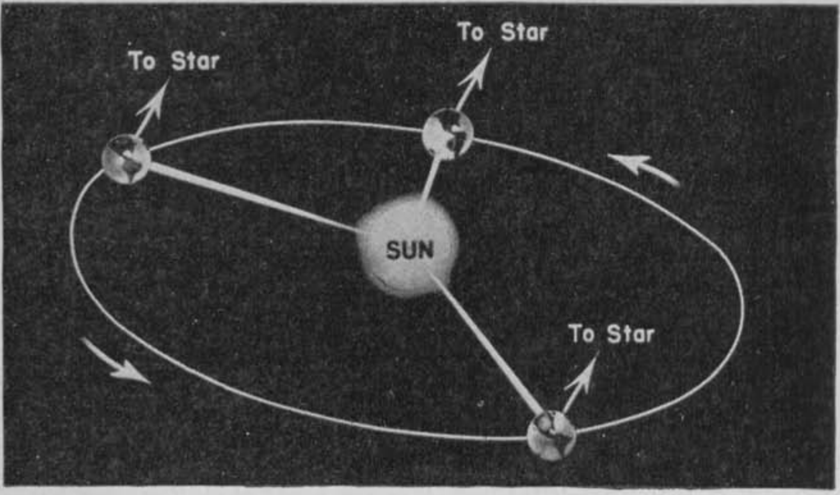



*Figure 102. Transit of the sun and a star.*

## 158. Mean or civil time

(Local mean time and local civil time are synonomous terms.)

The invention of clocks made a regular time necessary. Since apparent time varies from day to day, it was impossible to construct a clock that would keep apparent time. Mean or civil time is time based on an *average* solar (sun) day. This *average* day is based on a fictitious body, the "mean sun," which is an average sun that will cross the observer's meridian every 24 hours, exactly on the hour. This mean sun regulates time exactly, so that clocks will indicate a uniform time. The mean sun is sometimes ahead and sometimes behind the real sun but at the end of 1 year the number of hours elapsed of mean time and apparent time are exactly the same. Apparent time may be determined from mean or civil time by applying a correction known as the equation

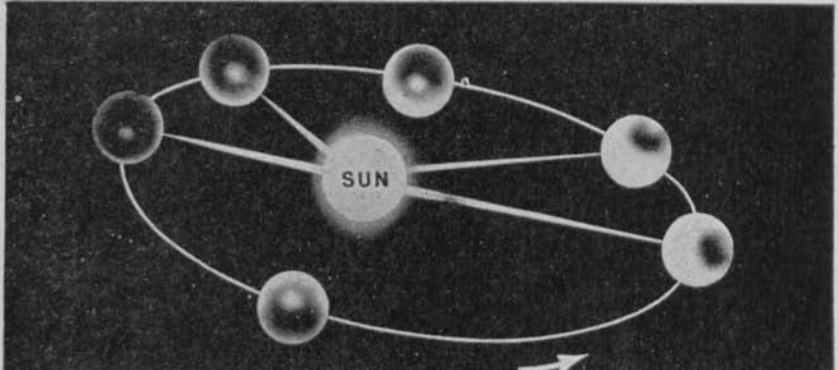



*Figure 103. Variable distances of earth from sun throughout the year.*

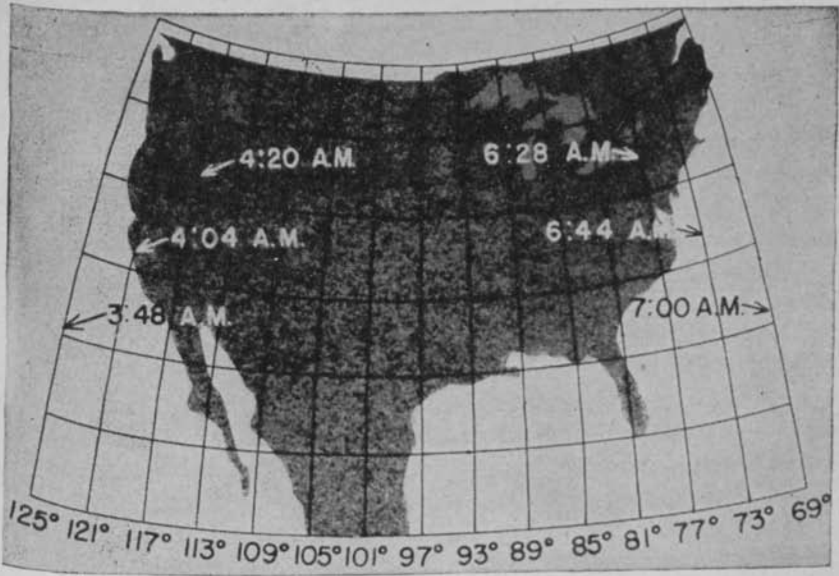



*Figure 104. Difference of time based on local meridians.*

of time to mean time. The equation of time is merely a tabulation of the difference of the two times in minutes and seconds of time. The value of the equation of time may be found in the sun tables of the American Nautical Almanac. An approximate value of the equation of time may be found in table II, appendix I. This approximate value is suitable for use with the bearing charts but is not accurate enough for precise observations.

## 159. Greenwich civil time

All the times mentioned previously are time based on a local merid-


*Figure 105. Standard time zones in vicinity of Greenwich.*

ian or an observer's meridian. Obviously, an observer in New York will see the celestial sphere and the sun in a different degree of rotation than will an observer in San Francisco if they are observing at the same instant. Therefore, the apparent time and the mean time for both observers are different because of the difference in longitude between the two positions. With military operations being carried on in widely separated points over the earth it is important that a message designate a particular instant so that an observer in one part of the world will know exactly what instant an observer in another part of the world is indicating. The navigator's problem is similar to that of the military problem. For that reason, the Greenwich Civil Time is chosen as a basis for a *universal* time because Greenwich Civil Time is the time as indicated on the 0° longitude meridian. A correction for longitude of an observer enables an observer any place on the earth to determine his apparent time, mean time or standard time from Greenwich Civil Time. Greenwich Civil Time is therefore used as the basic time for military or navigational units, and data in the American Nautical Almanac are based on this time.

## 160. Standard time

Standard time is a system of civil time to simplify time calculations over the earth. A section of the earth approximately 15° wide in longitude is given the same time throughout the 15° width. In this manner everyone in the 15° time zone has the same time. Standard time is based on Greenwich Civil Time, that is, the 0° meridian (Greenwich

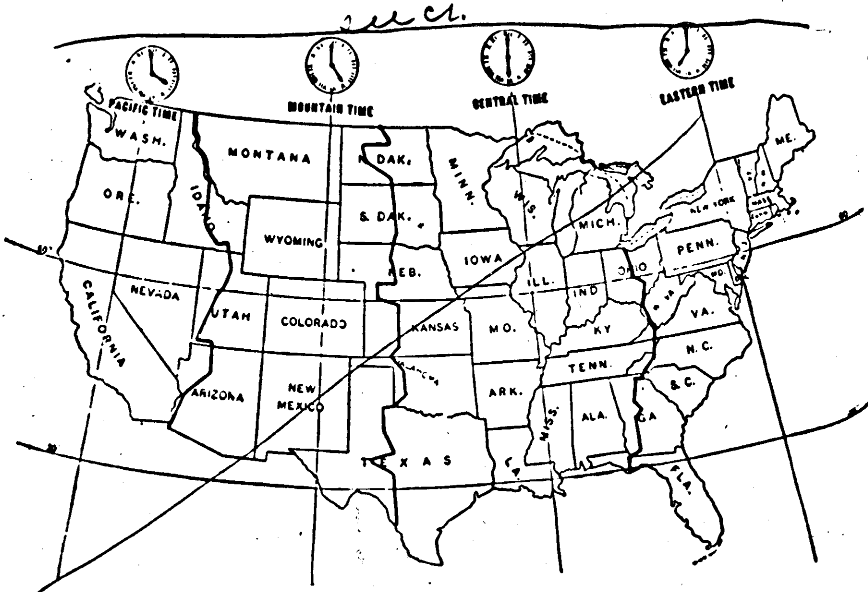



*Figure 106. Standard time zones in the United States.*

meridian) is chosen as the basic meridian. A belt 7° 30′ wide on both sides of the 0° meridian is given a time called Greenwich Standard Time which is numerically the same as Greenwich Civil Time. Then each 15° zone on either side of the Greenwich Standard Time zone is given a time one hour different from the Greenwich Standard Time as shown in figure 105. These 1-hour increments are carried continuously around the earth so that in the United States the 75° meridian is the basic meridian for Eastern Standard Time, the 90° meridian is the basic meridian for Central Standard Time, etc., as shown in figure 106. Therefore to change Standard Time to Greenwich Standard Time (or Greenwich Civil Time) it is only necessary to determine the closest 15° meridian to an observer's position and correct that time by the number of hours (the number of time zones) back to Greenwich. In other words, an observer of longitude 80° west is closer to the 75° meridian than the 90° meridian so his standard time is that of the 75° meridian. $75° \div 15° = 5$, showing that there are five time zones back to the Greenwich time zone. The correction to convert to Greenwich Civil Time is then 5 hours. The correction can be either plus or minus in sign. Rather than remember

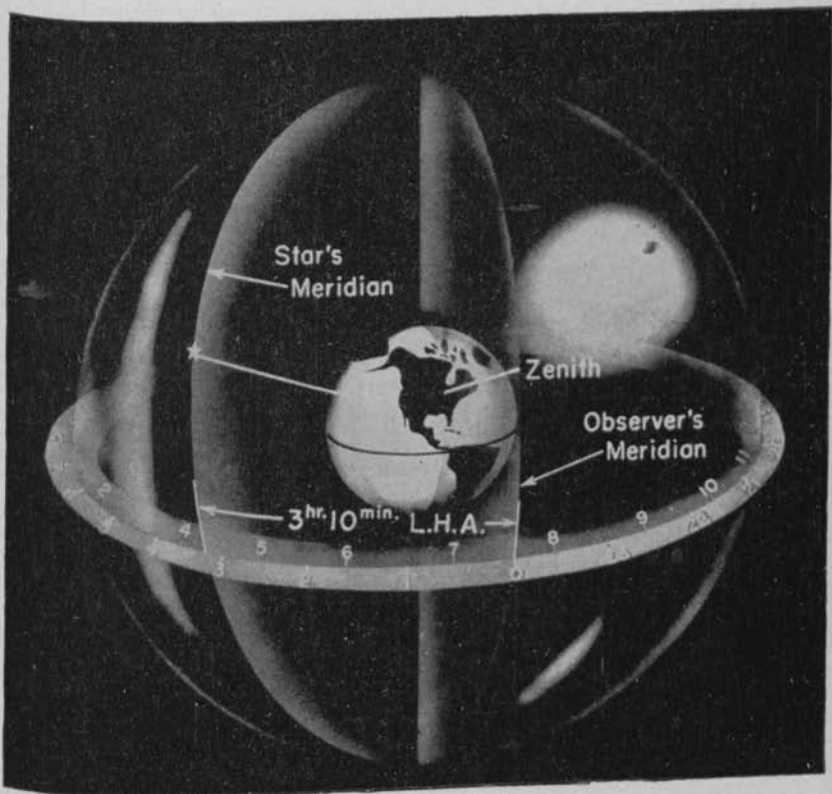



*Figure 107. Hour angle of a star.*

a rule for adding or subtracting hours depending upon whether a position is east or west of Greenwich, it is better to visualize the position of the sun with respect to Greenwich. For example, in this case the 75° meridian is west of Greenwich. The sun rises in the east so the sun passes Greenwich before it passes the 75° west meridian. Therefore, the time at Greenwich is later than the time at 75° west. Therefore, the 5 hours must be added to the Eastern Standard Time to obtain the Greenwich Civil Time.

## 161. War time

War time is merely a time 1 hour ahead of standard time. For example, Eastern War Time is 1 hour ahead of Eastern Standard Time.

## 162. Local time

Local time may be local sidereal, local apparent, or local civil (mean) time. The designation local merely means that this kind of time is based on the time at a local meridian (observer's meridian) rather than some standard meridian. For example, an observer at 73° W longitude has Eastern War Time indicated on his watch. If this time is indicated

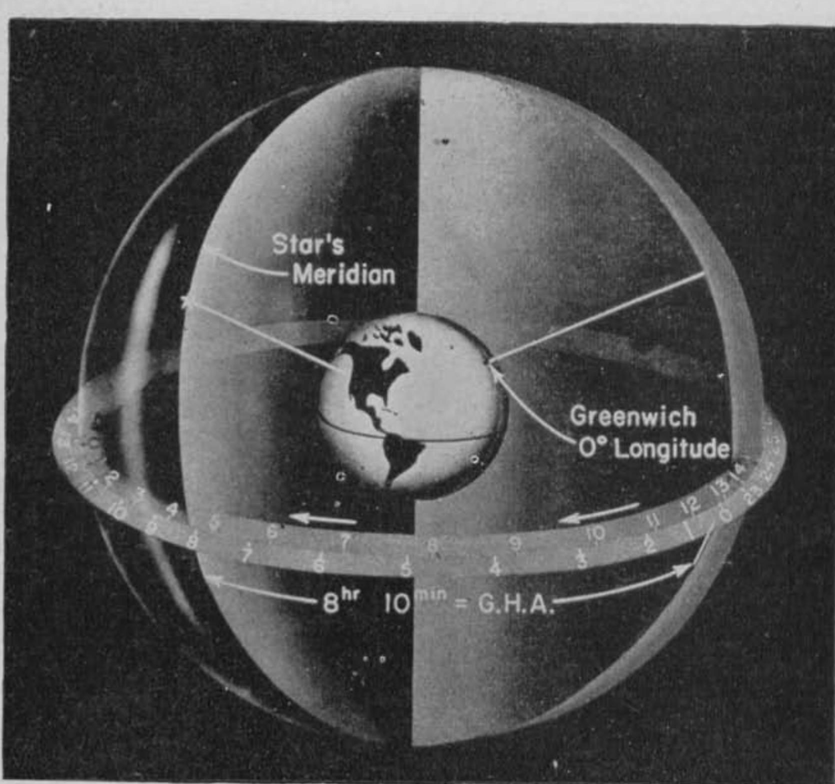



*Figure 108. Greenwich hour angle of a star.*

as 1100, he subtracts 1 hour to get the Eastern Standard Time of 1000. This is the standard time for the 75° time zone or the local civil (mean) time for the 75° meridian. Since the observer is at the 73° meridian, which is east of the 75° meridian, the sun passes the 73° meridian before it passes the 75° meridian, so the local civil or local mean time is later than the standard time.

$$15° \text{ of longitude} = 1 \text{ hour or } 60 \text{ minutes.}$$
$$2° \text{ of longitude} = 2/15 \times 60 = 8 \text{ minutes.}$$

Therefore the local civil time at the 73° meridian is 1000 + 08 = 1008. Local apparent time is the time as determined by the real sun at the local meridian and local sidereal time is the star time as determined by the vernal equinox at the local meridian.

## 163. Summary

*a.* Sidereal time is time determined by the position of the vernal equinox. Sidereal time can be changed to solar time but requires the use of a Nautical Almanac.

*b.* Apparent time is determined by the position of the real sun. Apparent time can be changed to Greenwich Civil Time, standard time,

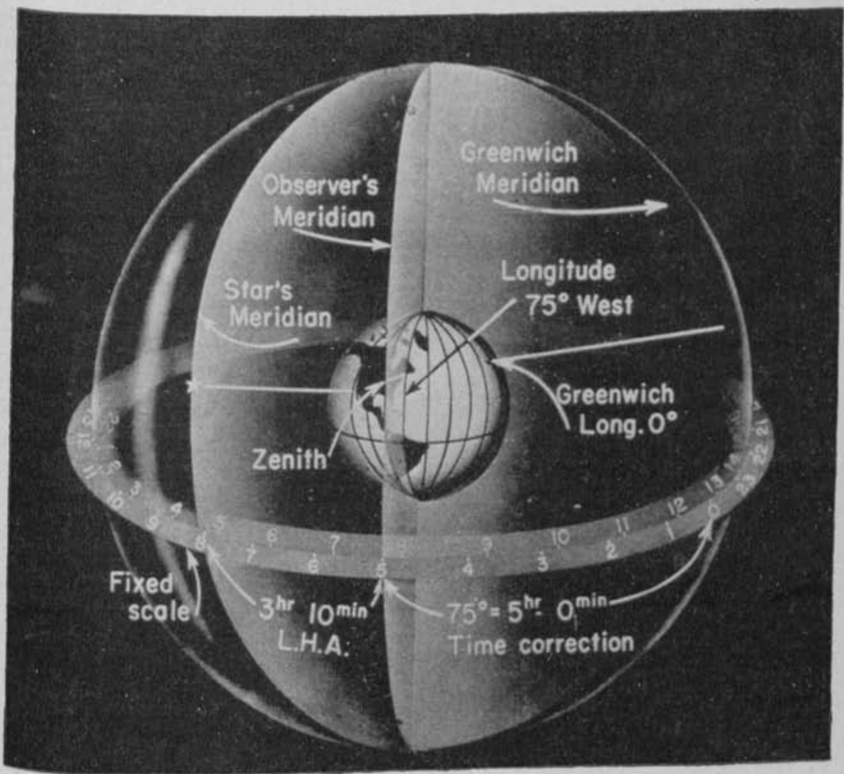



*Figure 109. Derivation of local hour angle.*

local mean time or war time by correcting for the equation of time (found in the Nautical Almanac) and correcting for longitude.

*c.* Mean time is time determined by the position of the mean sun. Mean time can be changed to apparent time by correcting for equation of time. Mean time can be changed to Greenwich Civil Time, standard time or war time by correcting for longitude.

*d.* Greenwich Civil Time is time determined at the Greenwich meridian by the position of the mean sun. This time may be changed to local mean time or any standard time by correcting for longitude. It can be changed to local apparent time by correcting for longitude and the equation of time.

*e.* Standard time is time determined by the position of the mean sun as referred to some standard meridian. It can be changed to Greenwich Civil Time, by correcting for longitude from the standard meridian to Greenwich meridian. It can be changed to local mean time by correcting for longitude and to local apparent time by correcting for longitude and the equation of time.

*f.* War time is 1 hour faster than standard time and can be changed to other times in the same way as standard time after deducting the one hour.

*g.* Local time is time referred to a local meridian. Correcting for longitude changes it to some standard or mean time.

## Section IV. TIME AND HOUR ANGLE

### 164. Greenwich hour angle

The American Nautical Almanac lists the hour angle for various celestial bodies as referred to the Greenwich meridian, and using Greenwich Civil Time. This method allows a great amount of data to be presented in a form so that an observer may convert the data to fit his position and his time. The hour angle of a star is the angle between the plane of the observer's meridian and the hour circle through the star. (See fig. 107.) The Greenwich hour angle of a star is then the hour angle of a star referred to the Greenwich meridian as shown in figure 108. This Greenwich hour angle is the angle given in the Nautical Almanac for a specified Greenwich Civil Time.

### 165. Local hour angle

The observer in the field requires the hour angle of the star seen by him at his meridian, and using his time. To find these data he con-

verts his time (usually standard time or war time) to Greenwich Civil Time and finds the Greenwich hour angle for the body for that particular time. He then corrects this Greenwich hour angle by the amount of the correction for his longitude which gives him the local hour angle for his particular position. Figure 108 shows the Greenwich hour angle and figure 109 shows the correction of 5 hours 00 minutes for his longitude 75° west and shows the local hour angle 3 hours and 10 minutes which he derives.

# CHAPTER 11

# AZIMUTH DETERMINATION—APPROXIMATE METHODS

## Section I. GENERAL

### 166. Azimuth

One of the primary duties of a reconnaissance officer is to furnish his unit with orienting lines for all material requiring them. If two intervisible points whose coordinates are known are located in the vicinity, or if a line of known azimuth is available, the problem is simple. But if these data are not available it becomes necessary for the reconnaissance officer to determine an azimuth by some other means. This determination of azimuth is an important and exacting phase of orientation and the method employed may be dependent upon the availability of special data such as precise time, nautical almanacs and so forth. It is essential, therefore, that the reconnaissance officer be thoroughly familiar with several methods of obtaining azimuth so that in an emergency he is able to produce results even under adverse conditions. The methods described in this chapter are not precise methods but enable the reconnaissance officer to obtain approximate azimuth when he does not have an almanac, instruments, or precise time.

## Section II. COMPASS

### 167. Use

There are in general use, several simple devices for approximate determination of the meridian. The most common of these is the compass, the use of which does not depend on any astronomic principle but simply on the magnetic attraction of the earth's mass. The magnetic needle, when allowed to swing freely, comes to rest in the magnetic meridian. The magnetic poles are not coincident with the terrestrial poles

(see fig. 38); therefore the magnetic needle seldom points true north and south. The angle between the true meridian and the magnetic meridian is called *magnetic declination.* The mean values of the declinations in different areas are shown by *isogonic lines,* connecting points of equal declination. If the magnetic needle points east of true north it is said to have an *east declination;* if west of north, a *west declination.* Many types of compasses are provided with a movable dial in order to set off proper declination. In other types, it is necessary to correct the reading by the value of the declination.

### 168. Compass errors

Directions obtained by the compass are subject to serious errors due to local attraction. In some cases, particularly in mountainous country where iron ore may be present, the magnetic needle cannot be used. In high latitudes the declination becomes so great that without a precise isogonic chart, the direction indicated is too much in error to be used. The close proximity of electric wires, railroad tracks, guns or trucks will seriously affect the readings. Metal objects worn or carried on the personnel using the compass will cause the compass to give erroneous directions. This includes personal paraphernalia. Helmets, weapons, pocket knives, and cartridge belts must be removed. The compasses used in self-propelled mounts or trucks may be adjusted to give fairly accurate direction temporarily but after a few miles of driving, the adjusting mechanism may jostle off-so that the direction indicated is in error. Also, any movement of guns, loading or expenditure of ammunition will require a readjustment. A compass may be taken away from any mass of metal a distance of 200 feet, being careful that there is no steel object carried on the person and by using an isogonic chart or correcting for declination from a map of the area, an accuracy within 1° may be obtained. Without knowledge of the declination of the needle for a given area, an error of 30° may be made with a compass.

## Section III. WATCH DIAL

### 169. Method

In the Northern Hemisphere, if the hour hand of a watch is pointed at the sun, a line bisecting the smaller angle between the hour hand and the 12-hour graduation, points approximately south. In the Southern Hemisphere, if the 12-hour graduation is pointed at the sun, a line bisecting the smaller angle between the 12-hour mark and the hour hand

*Figure 110. Determining direction with a watch dial.*

points approximately north. A match may be held vertically over end of the hour hand (or the 12-hour mark) and the shadow of the match used to line the watch properly. (See fig. 110.) This method will work only when the watch is set to standard time. If the watch is operating on war time the results will be in error. This method may give an accuracy within 5° at some time of the year but may be in error as much as 10° at other times. This method is inapplicable when the sun's declination is nearly the same as the latitude of the position.

*Figure 111. Erecting gnomon.*

## Section IV. SHADOW OF A GNOMON

### 170. Method

Direction may be determined by the sun by setting up a rough gnomon similar to the type used on a sundial. Select a long pole and erect it as shown in figure 111 so that it leans in a northerly or southerly direction (north in Northern Hemisphere, south in Southern Hemisphere). Suspend a weight by a string from the end of the leaning pole. (See fig. 112.) Drive a stake directly under the suspended weight. About an hour before the sun reaches the zenith, drive a stake at the end of the shadow of the leaning pole (gnomon). Using the distance between the two stakes as a radius describe an arc about the stake under the suspended weight. (See fig. 115.) When the shadow of the pole again touches the arc (after 1 or 2 hours), drive a stake at the point of contact. (See fig. 116.) Divide the distance between the two stakes on the arc, into two equal parts. A straight line joining the midpoint of the line between the stakes and the stake under the suspended weight will be a line pointing approximately true north in the Northern Hemisphere or true south in the Southern Hemisphere. (See fig. 117.) In certain times of the year in the vicinity of the Equator the direction may be reversed because although the observer is in the Northern Hemisphere, the sun is farther north, resulting in a southern direction. The indicated direction will be exactly 180° off however, which should be

*Figure 112. Suspending weight from gnomon.*

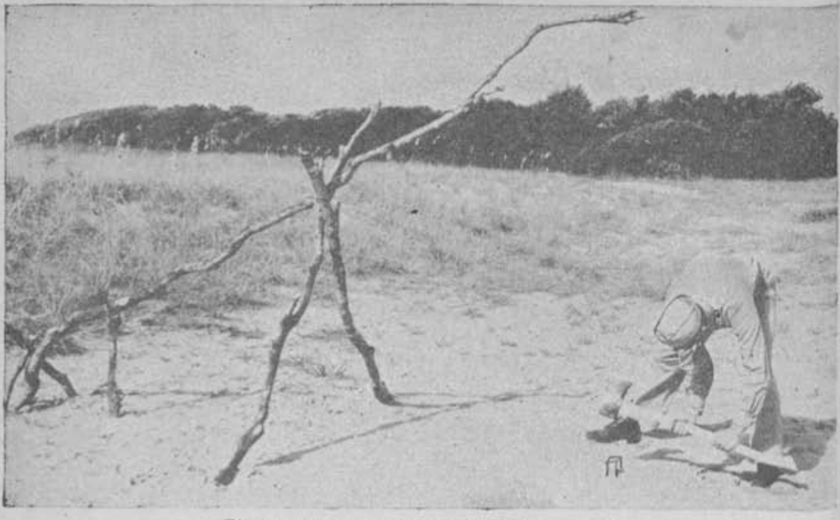


*Figure 113. Stake is driven under weight.*

apparent to the user of this method. An accuracy of 1° may be attained by careful performance by this method.

*Figure 114. Stake at end of shadow.*

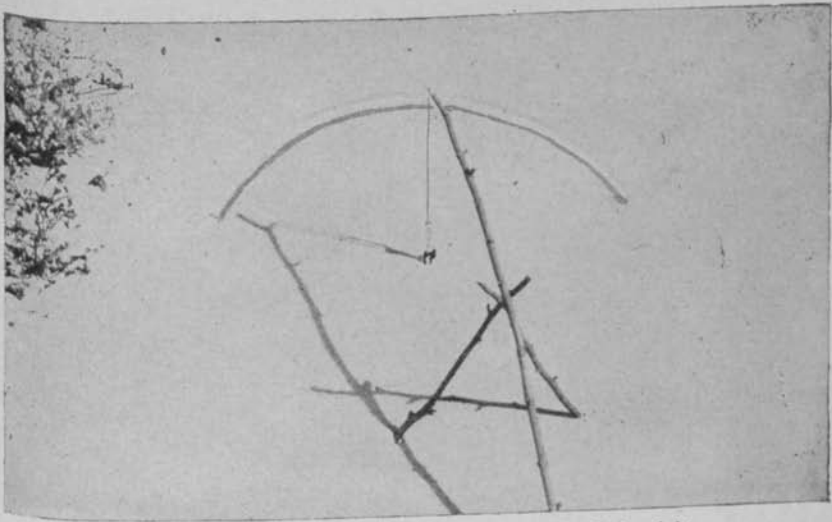


*Figure 115. Arc described about stake at suspended weight.*

## Section V. DIRECTION BY PLUMB LINE AND STAR

### 171. Polaris

A plumb line may be used as an elementary form of transit to sight on a star. Erect two frames similar to those shown in figure 118. These frames should be erected in such a manner that the line between the

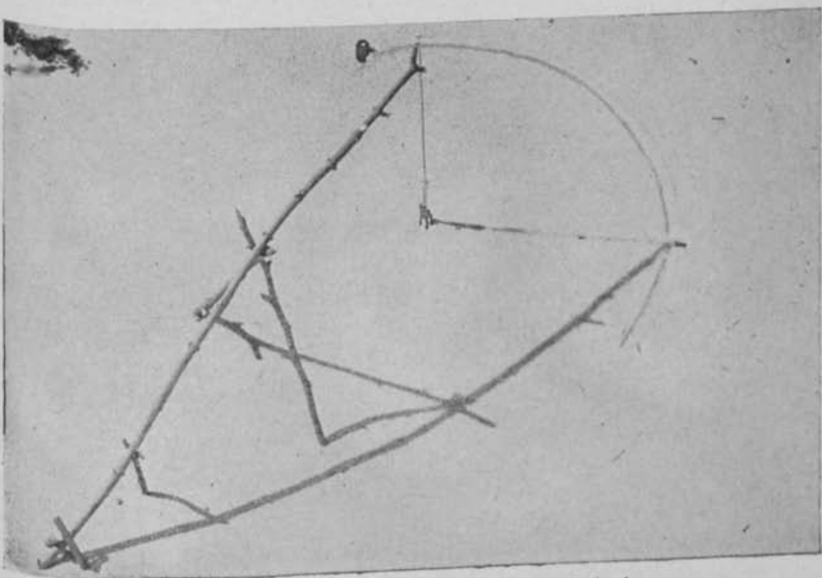


*Figure 116. Stake at intersection of arc and shadow.*

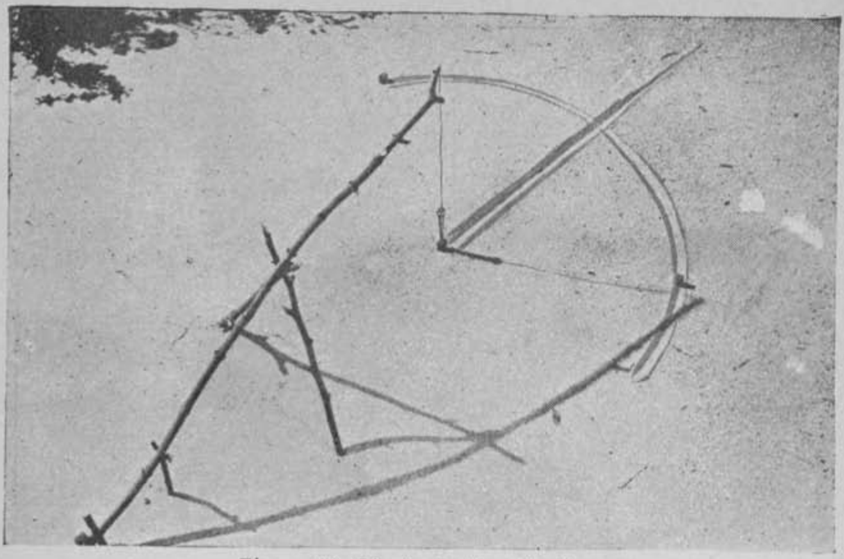


*Figure 117. Line indicating direction.*

two plumb bobs will be in line with the star Polaris. Suspend a plumb bob from each of the two frames and then have an assistant move one of the two plumb bobs so that the strings of the plumb bobs will be in line with the star Polaris as shown in figure 118. The line between the two plumb bobs will be an indicator or true north. As the probable error of this method is 1°, and as Polaris has an orbit within 1° of the north celestial pole, a sight taken on the star Polaris at any time will always be within 2° of true north except in exceptionally high latitudes. Polaris may be found by following the pointers of the Big Dipper shown in figure 120.

## 172. Any bright star

The same method of establishing a line of known direction by plumb bobs may be used with any first magnitude star. Use the bearing chart of the stars in appendix I to determine the direction of a star at a predetermined time. At this time line up the plumb bobs with the selected star and the line between the two plumb bobs will be the direction determined by the charts. This method will give a direction accurate within 1½° if the plumb bobs are carefully placed.

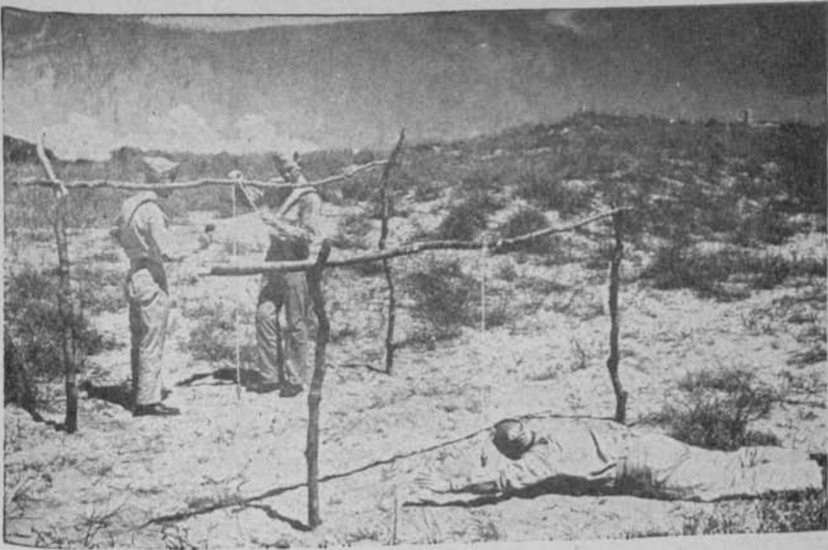


Figure 118. Lining plumb bobs with star.

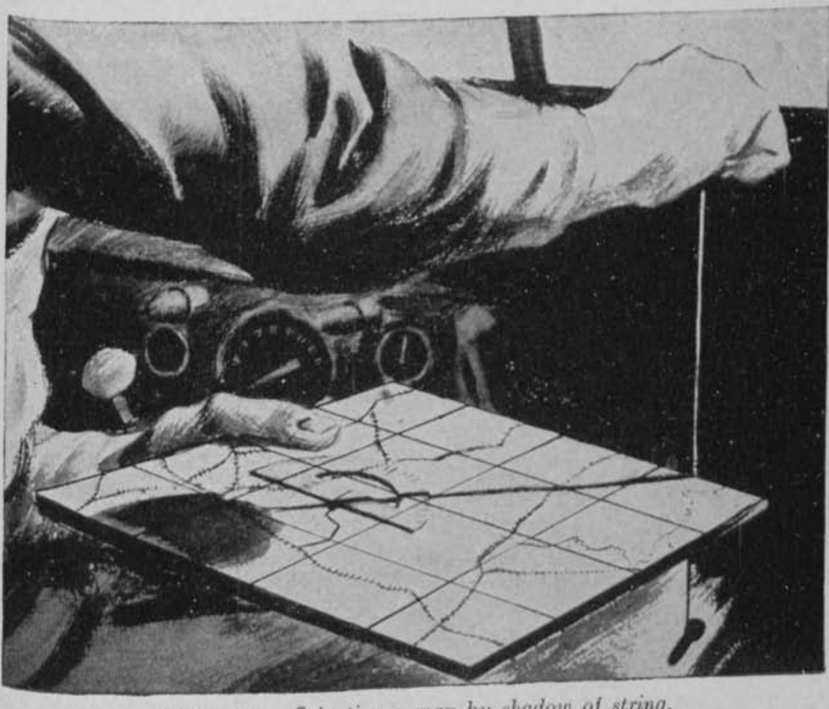


Figure 119. Orienting a map by shadow of string.

## 173. Method

Determine the bearing of the sun at some future time by means of the bearing chart of the sun (app. I). Suspend a weight from some form of framework so that the string holding the weight makes a shadow on the ground. At the time previously selected for use in calculating the bearing, mark the line of the shadow on the ground. The line of the shadow *from the point marked to the point under the suspended weight* has the same bearing as the bearing of the sun previously determined. This method permits determination of direction in high latitudes where the "Midnight Sun" is encountered and is usable in either hemisphere. A method of orienting a map by this principle is shown in figure 119. The shadow is made to cross the point on the map corresponding to the observer's position. The map is then turned until the protractor reads the same bearing as the bearing of the sun. The map is oriented when the bearings are the same. It should be noted that the bearing charts of the sun or of the stars cannot be used if approximate latitude and longitude are unknown.

# CHAPTER 12

# STELLAR OBSERVATION

## Section I. GENERAL

### 174. General

Before undertaking any survey operations, the observer and the recorder must have enough practice to gain some skill in their work, to form certain habits of procedure which insure accuracy in the results, and to learn to choose the method best suited for the work at hand. Signals, targets, and rods are immovable while being observed, but celestial bodies appear to move, often quite rapidly. This makes the pointing more difficult, and in some systems of observation the exact time of centering has to be read and recorded. The use of the prismatic eyepiece and working at night seem strange at first. Computations are perhaps more varied than in ordinary survey work, and often seem rather abstract to the beginner. However, if the movements of the celestial bodies are kept in mind the reasons for the various computations are apparent.

### 175. Equipment

Before taking the field, the following must be prepared or arranged in advance:

Adjusted instrument.
Known error of watch.
Flashlights, if at night.
Almanac (current year). Required for hour angle methods.
TM 5–236 (Tables).
Notebook and blank forms.
Descriptions of stations to be occupied and observed.
Illumination for mark (if at night).

### 176. Adjustment of transit

The instrument should be in good adjustment. The plate bubbles should have special attention, as the only error not overcome by the combination of direct and reversed readings is the deviation of the vertical axis from the plumb line. Some observers prefer to rely upon

the striding level or telescope level for the final leveling of the instrument. This method is advisable when altitude methods of observation are being used. In most of the systems, the instrument cannot be releveled during a set of observations (one direct and one reversed). The tripod should be located so as to be least in the way during the observations. As most transits have no interior illumination for the cross-hairs at night this is accomplished by having an assistant direct a flashlight, held at such distance as to secure the desired intensity, at a piece of white paper inside of and extending beyond the sunshade. This flashlight must be shielded from the observer's eye. Some transits are equipped with a sunshade having a reflecting plate inside the shade for use when making star observations.

## 177. Watch

The watch should be preferably one with a sweep second hand. The watch error to the nearest second must be known (this can be obtained from radio time signals where these are available). The minute hand should be set to the nearest minute, and in exact correspondence with the second hand, reading the even minute when the second hand is at 60. No attempt should be made to set the second hand. The recorder does not attempt any computations during observation. He is responsible for the observer following the prescribed program, for immediately requesting a check on any readings which seem discordant, and for reading the second of each observation if precise time is used. When the observer calls, "Ready," the recorder starts counting the seconds on the watch to himself. When the observer calls, "Take," at the instant of centering, the recorder immediately records the time and is then ready to repeat and record the vernier reading reported by the observer.

## 178. Field notes

A notebook is carried at all times, in case the desired blank forms are not at hand. The forms should have spaces for recording the data on observations. Most of the azimuth observations are made in three separately computed sets, each of one direct and one reversed observation. If these do not provide at least two sets giving close check, the observations are repeated. The recorder is responsible for advising the observer when to reverse, when readings do not check, and for keeping the time.

## 179. Focus of telescope

In all astronomic observations, the telescope must be focused for infinity so as to give the sharpest possible image of the celestial body. As the focus should not be changed during the observations, the signal or lighted mark is placed at such distance that the focus will not have to be changed when sighting at it. The mark is placed as far from the

instrument as possible to insure precise alignment, however, 1/4 mile will usually be sufficient. For accuracy in pointing, the terrestrial object should have as small an aperture for light as can be seen clearly. A signal box containing a flashlight or bulb and dry cells with an adjustable vertical slit or series of slits of various width, one of which can be accurately plumbed over the stake of the mark while the light is directed exactly toward the instrument is prepared. If such a box is not at hand, a bare flashlight bulb may be used.

## 180. Choice of celestial body

During daylight hours, the sun is the only celestial body that can be readily observed. On dark days such as occur in the winter, some stars can be observed through the telescope of the transit. Polaris is the most easily identified star in the Northern Hemisphere and has a very slow movement. However, because Polaris cannot be seen in so many parts of the Northern Hemisphere due to local weather conditions, and because it cannot be seen in the Southern Hemisphere, it is inadvisable to depend on using this star for observation. Methods of identification of stars, which will enable the user to identify any first magnitude star, are presented in appendix I. The choice of star to use is determined by the method of observation to be used. That is, if the altitude of a star is to be measured, it is best to select a star whose altitude is changing slowly as compared to its change in azimuth. If an hour angle method is to be used the star selected is one that is changing azimuth very slowly, so that a small error in time causes a very small error in azimuth. First magnitude (bright) stars are so well scattered throughout the celestial sphere that an observer must not be tempted to use a star in an unfavorable position. Observation can be made and the star identified later if necessary. All artillery officers who are likely to have any task requiring azimuth determinations must be familiar with the more common stars and their relative positions in the sky.

## 181. Choice of method

*a.* The primary consideration in selecting a method of determining azimuth are the time at the disposal of the observer, the instruments available for his use, his knowledge of the correct time, and his experience in astronomic work. The secondary consideration is the degree of accuracy desired. If the data are required to establish an orienting azimuth for laying a gun, the accuracy desirable depends somewhat on the type of gun, the mission, and upon the degree of coordination that is to be exercised between that unit and adjacent units. If the data are required on short notice during daylight, some method of solar observation is necessary. These methods are covered in chapter 13.

*b.* If azimuth is required for the adjustment of a traverse line in connection with the location and orientation of a battery, the maximum

| Method | Advantages | Disadvantages |
|---|---|---|
| Polaris at elongation | Allows sufficient time for repetitions. Simple calculations. Time of observation unnecessary for calculations. | Observations must be taken at specific time and only one observation possible in 12 hours. Usable only in Northern Hemisphere. |
| Polaris at any time | Any number of observations permitted. Observations at any time during darkness. Relatively simple calculations. | Precision of about 1 minute of azimuth. Method usable only in Northern Hemisphere. |
| Any star (equal altitudes) | Time of observation unnecessary. May be performed in either hemisphere. Practically no calculations. Instrument and refraction errors eliminated. No tables required. | Observation may be lost due to clouds obscuring star. Observations must be taken 5 to 8 hours apart. |
| Any star (altitude method) | Time of observation unnecessary. Any number of observations permitted. Simple calculations. Almanac unnecessary. May be performed in either hemisphere. | Requires correction for refraction. Requires more skillful instrument operation. |
| Any star (hour angle method) | Most precise method. Any number of observations can be made. Usable in either hemisphere. Refraction corrections unnecessary. | Requires time within precision of 6 seconds. Requires an almanac. More difficult computations. |
| Bearing chart of the stars method. | Fast and easily computed. Precise time unnecessary. Usable in either hemisphere. Any number of observations may be made. Almanac unnecessary. Excellent for coordination of adjacent units. | Error of 1+1/2° may be made. Latitude and longitude of position must be known. |
| Solar (hour angle method) | Observations can be made in daytime. Several observations can be made. Method can be used in either hemisphere. | Time must be accurate to 5 seconds. Results accurate to 1 minute. Long calculations required. Requires almanac. |
| Solar (altitude method) | Same as above. Time within 15 minutes is all that is required. | Same as above except for time. Instrumental errors introduced. |
| Bearing chart of the sun method | Fast and easily computed. Time within 3 minutes sufficient. Usable in either hemisphere and will compute "midnight sun." Almanac unnecessary. Excellent for coordination of units. | Error of 1° may be made. Latitude and longitude of position must be known. |

error should be less than 2 minutes of arc. If there is no particular urgency in time, the observer may wait until darkness and make a star observation.

*c*. If a precise azimuth is required, solar observations should not be attempted. Stellar observations using the altitude method or hour angle method give results within the limits of accuracy of the best transit.

*d*. The table on page 158 outlines the advantages and disadvantages of taking observations by the principal methods:

## Section II. POLARIS AT CULMINATION AND ELONGATION

### 182. Identification of Polaris

Polaris is very close (within about 1°) to the North Celestial Pole. As a result, Polaris has a very small apparent movement in the course of a day. Polaris is readily identified by the "pointers" of the Big Dipper which are the two stars forming the outside of the cup of the dipper. A line through these two stars ($\alpha$ and $\beta$ of Ursa Major) very nearly passes through the star Polaris as shown in figure 120. Polaris is the only bright star in this general area, and is approximately half way between the Big Dipper (Ursa Major) and the constellation Cassiopeia.

### 183. Culmination and elongation

Polaris appears to revolve around the North Celestial Pole in an orbit of roughly 1° radius. The position of the star in relation to the celestial pole is given a name for certain specific positions. The point along the

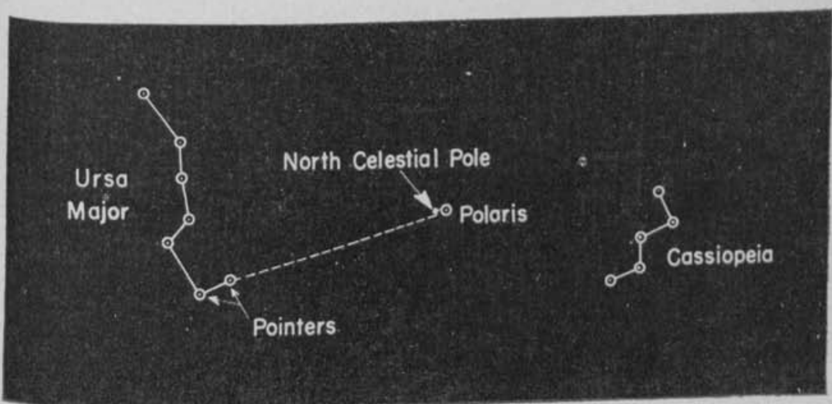



*Figure 120. Pointers of the star Polaris.*

orbit at which Polaris is the farthest east is called the eastern elongation of Polaris, shown in figure 121. The point at which Polaris is the farthest west is called the western elongation of Polaris. Likewise, when Polaris is directly over the North Celestial Pole, Polaris is at upper culmination and is at lower culmination when Polaris is directly below the celestial pole. The positions of elongation and culmination are not exactly 90° apart due to the convergence of the hour circles tangent to the orbit of Polaris and as a result the time of culmination is not exactly six hours after an elongation. Elongation is indicated approximately by the positions of the Big Dipper and Cassiopeia. Polaris is on the same side of the North Celestial Pole as is Cassiopeia and is in line with the "pointers" of the Big Dipper. Therefore, when the line of the pointers is almost horizontal, Polaris is near elongation and is on the same side of the celestial pole as is Cassiopeia. (See fig. 121.)

## 184. Advantages and disadvantages at culmination

The main advantage of making an observation for azimuth at either upper or lower culmination, is that Polaris is directly above or below the North Celestial Pole at this time, so that the observation instrument will be pointed directly north when sighted at the star. A secondary advantage is that no computations or measurements are required when

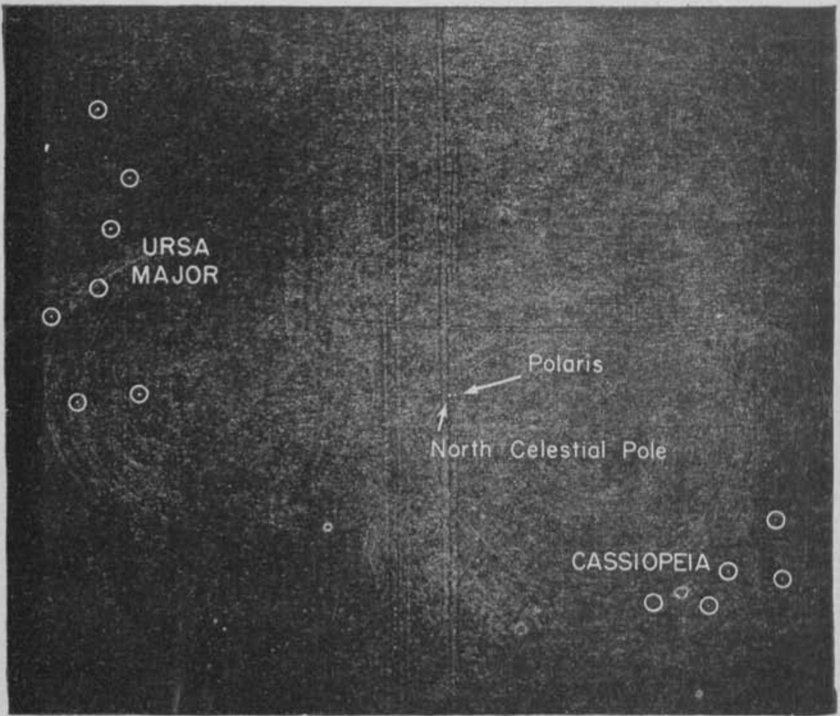



*Figure 121. Polaris at eastern elongation.*

sighting on Polaris at culmination. The disadvantages are that the observation must be made at a precise instant for a very precise direction, the time of culmination must be known, and no time is permitted for a double setting of the instrument on the star as a check. An observation made by the method following should not be expected to be more accurate than 5 minutes of angle if the correct time is known within a precision of 2 or 3 minutes.

## 185. Determination of time of culmination

The time of culmination of Polaris may be determined from the American Nautical Almanac if available. However if an almanac is not available, the time may be determined very closely by means of sheet 1 of chart II (app. I). Upper culmination takes place at 0145 local sidereal time. (The time actually varies from 01:44:02 to 01:46:41 in the year 1944 and the average sidereal time will be about 27 seconds later for each succeeding year.) Lower culmination takes place at 1345 local sidereal time. To determine the watch time of a culmination, lay a straightedge on sheet 1 of chart II (app. I). Set the right end of the straightedge at the point on line *C* corresponding to the date and set the straightedge so that it intersects line *B* at 0145 or 1345 the local civil time of upper culmination will be indicated on line *A* when line *B* setting was 0145. Local civil time of lower culmination will be indicated on line *A* when line *B* setting was 1345. This local civil time must be changed to standard time in use or Greenwich Civil Time by correcting for longitude of the position by means of table I (app. I). A practical problem is described in paragraph 242 illustrating the method of changing the local civil time to a standard time. The time of culmination so determined is an approximate time but is sufficiently accurate to allow a determination of azimuth within 5 minutes of angle.

## 186. Procedure ~~of~~ at culmination (parc 3)

The transit should be set up over the point from which an azimuth is to be determined several minutes before culmination. Set the horizontal scale to zero. Loosen the lower motion screw and set the telescope so that the vertical cross hair is near the star. Tighten the lower motion screw and set the vertical cross hair exactly on the star by means of the lower slow motion screw. Follow the star in azimuth by means of the lower slow motion knob until the timekeeper calls "Time" (when the watch reads the time previously computed as the time of culmination). When the timekeeper calls "Time," all movement is stopped and the telescope and zero of the horizontal scale will be pointing at the north celestial pole or zero azimuth. There are no computations or adjustments to be made. The expected accuracy should be within 5 minutes of angle.

## 187. Advantages and disadvantages at elongation

The advantages of making an observation on Polaris at elongation is that for several minutes Polaris appears to move in a vertical direction but not in a horizontal direction. At this particular time, several observations may be made to correct for instrumental errors without making an error in horizontal angle of direction. Also, when Polaris is at elongation, the exact distance from the celestial pole is known so that the time or hour angle of the star is unnecessary, thereby simplifying computations. The disadvantages of making an observation at elongation are that there will only be one opportunity for observation in a 12-hour period and maybe only one in a 24-hour period if one elongation takes place in the daytime. The star may be obscured by clouds at the time of elongation and elongation may take place at an inconvenient hour. True north must be computed from the direction observed.

## 188. Procedure at elongation

*a.* The transit is set up over a stake, on the station from which direction is to be determined, leveled, and the focus adjusted for observation at distant object, prior to the time when the constellations are approaching the position indicative of the elongation of Polaris.

*b.* When Polaris is approaching the position of elongation, focus the telescope on the star and bisect it with the vertical cross hair. Follow the star in its horizontal motion, by means of the slow motion screw until the star no longer changes its bearing but moves vertically. As soon as this occurs, lower the telescope and set a point in line with the vertical cross hair, at a distance of several hundred feet from the transit. Immediately after setting this point, reverse the instrument and repeat the operation, setting the second point on the same stake as the first. If there is any distance between the two points laterally, divide the distance between the two, in half, and the half point will be the correct bearing of Polaris. This operation of taking two sights and dividing the distance between the two points set, corrects for any error in the adjustment of the instrument.

*c.* The change of bearing of Polaris at elongation is only about 5 seconds of arc in 10 minutes time so that sufficient time is allowed for repetition of sights without losing the accuracy of bearing desired, if the work is carried out expeditiously.

*d.* The direction of the line set out in observation on Polaris at elongation is the bearing of Polaris and not true north. The bearing laid out on the ground must be corrected for the horizontal angle between the star and the pole to obtain true north. This angle is not equal to the polar distance of Polaris but may be found by the following formula:

$$\text{Sine stars true bearing} = \frac{\text{Sine polar distance of star}}{\text{Cosine latitude}}$$

*e.* The mean polar distances for the years 1943–1952 may be found in the following table. The latitude may be found from a reliable map or observation.

MEAN POLAR DISTANCES OF POLARIS*

| Year | Mean polar distance | Year | Mean polar distance |
|---|---|---|---|
| 1943 | 1°00′21″ | 1948 | 0°58′52″ |
| 1944 | 1°00′03″ | 1949 | 0°58′34″ |
| 1945 | 0°59′45″ | 1950 | 0°58′16″ |
| 1946 | 0°59′27″ | 1951 | 0°57′58″ |
| 1947 | 0°59′10″ | 1952 | 0°57′40″ |

*The above table is computed for January 1st of each year. An error of 18 seconds as a maximum will be involved if no corrections are made for the time of year. This value (18 seconds) however, is smaller than the least reading possible with a double sighting on the star with an issue transit, and so the values above may be used in computations as given.

*f.* The angle between true north and the line of direction of Polaris is the same angle as the True Bearing of the Star, shown in figure 122.

*g.* This angle is so small that a more precise setting of true north can

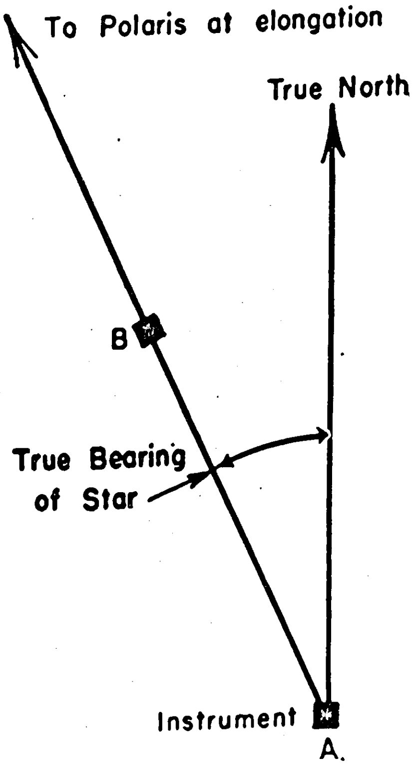



*Figure 122. Angle of Polaris at elongation.*

be made by computing the ordinate of the angle and measuring this ordinate to set true north. In figure 123, the line *AB* is the line established in the direction of Polaris at elongation. *AC* is the true north line desired. Angle *A* has been computed and is the true bearing of the star. The tangent of angle *A* is equal to $BC/AB$ or $BC = AB \tan A$.

*h.* The line *BC* is at right angles to *AB*. If the distance *BC* is measured at right angles to *AB*, the line *AC* will be true north. A convenient way of measuring this ordinate along a line at right angles to the line *AB* is by laying out a 3, 4, 5 triangle. A triangle having sides of 3 units, 4 units, and 5 units in length respectively will make a right triangle. By using a tape and three men to hold the tape at the corners of the triangle as shown in figure 124, a right angle is laid out at *B*. The ordinate distance is then measured along this line established at right angles to the line *AB* and the point *C* is set. The line *AC* is then a true north line.

*i.* Observation on Polaris at elongation is the easiest method for precise work as very little computation is necessary. It is unnecessary to know the time of elongation, as elongation can be determined by observ-

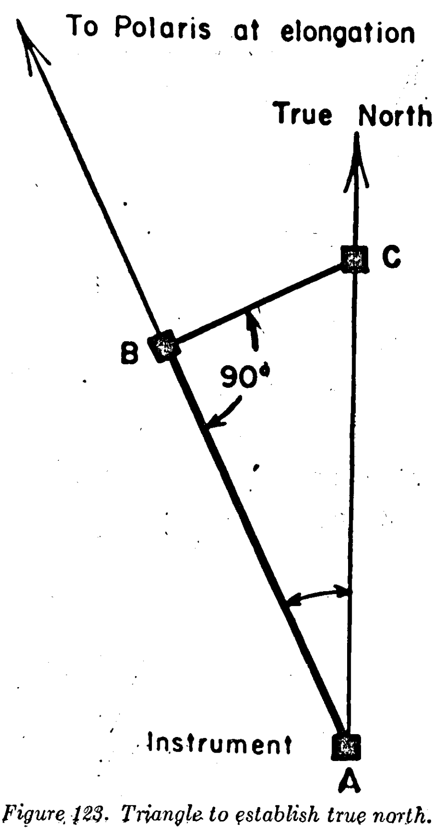



*Figure 123. Triangle to establish true north.*

ing the Big Dipper and Cassiopeia, and the exact instant of elongation can be observed by watching the travel of the star through the telescope. However, this method depends on the observation of one star, resulting in a limitation of its usage to one hemisphere, and to parts of that hemisphere due to terrain. Also, only one or two observations are possible in a 24-hour period. Under certain conditions, it will be impossible to wait for the time of elongation for an observation. The next method presented enables an observer to use Polaris at any hour.

## Section III. POLARIS AT ANY HOUR

### 189. General

The bearing of the star Polaris may be determined at any hour if the time is known and an American Nautical Almanac is available. This system requires but a limited knowledge of astronomy and simple calculations. These calculations can be worked with sufficient accuracy on a slide rule, or by the use of logarithms to the third place. Polaris appears to revolve around the north celestial pole in a radius of about 1°. The true radius may be determined from the Nautical Almanac by subtracting the declination of Polaris from 90°. The difference between the two will be the polar distance of Polaris.

### 190. Procedure

*a.* Center the transit over the station, and level accurately. Do not

*Figure 124. Laying out 3, 4, 5 triangle.*

change the leveling until a set of observations has been completed. The telescope is focused at infinity, the objective lens being almost completely back toward the eyepiece. Illuminate the cross hairs with a flashlight and adjust the eyepiece so that the cross hairs can be seen distinctly.

*b.* Set the *A* vernier at zero and sight on the mark, with the telescope in the direct position, using only the lower motion. Read and record the magnetic azimuth, to be used as a check.

*c.* Loosen the upper motion and turn the telescope to the star. In observing on Polaris, set the approximate latitude in degrees on the vertical circle, as that will be the approximate altitude of the star. When the star has been picked up, have the assistant illuminate the cross hairs and, when nearly sighted on the star, call "Ready" to the recorder. Additional focusing of the objective lens may be necessary to bring the star image to a single point of light. When the vertical and horizontal cross hairs are exactly on center of the star, call "Take." Recorder immediately records the time. Without moving the telescope, read and record the reading of the *A* vernier and the altitude of the star.

*d.* Loosen the lower motion, reverse the telescope, turn to the mark

| | |
|---|---|
| Station: *A* | Watch: 10 sec. fast |
| Mark: Station *B* | Estimated L.H.A. (check) |
| Date: 15 Sept 1943 | |

| Point sighted | Time | | | Vernier *A* reading | Angle | Vertical Angle |
|---|---|---|---|---|---|---|
| | *H* | *M* | *S* | | | |
| Mark (D) | | | | 0° 00′ | | |
| Star (D) | 16 | 46 | 11 | 65° 45′ | 65° 45′ | 33° 34′ |
| Mark (R) | | | | | | |
| Star (R) | 16 | 47 | 09 | 131° 30′ | 131° 30′ | |
| Average | 16 | 46 | 40 | | 65° 45′ 00″ | |
| Mark (R) | | | | 0° 00′ | | |
| Star (R) | 16 | 49 | 36 | 65° 44′ | 65° 44′ | |
| Mark (D) | | | | | | |
| Star (D) | 16 | 50 | 21 | 131° 30′ | 131° 30′ | 33° 36′ |
| Average | 16 | 49 | 59 | | 65° 45′ 00″ | |
| Mark (D) | | | | 0° 00′ | | |
| Star (D) | 16 | 51 | 57 | 65° 48′ | 65° 48′ | 33° 39′ |
| Mark (R) | | | | | | |
| Star (R) | 16 | 52 | 35 | 131° 35′ | 131° 35′ | |
| Average | 16 | 52 | 16 | | 65° 47′ 30″ | |

*b.* The method of deriving the local hour angle is shown in figure 125. The Greenwich hour angle at $0^{hr}$ Greenwich Civil Time (326° 35.6′) is added to the angular travel of the star in 20 hours 46 minutes and 30 seconds (312° 28.7′) to give the *GHA* at time of observation (639° 04.3′). 639° 04.3′ —360° = 279° 04.3′. The observer is at longitude 77° 33′ West so that the star is not as far advanced in rotation for his position as it is for Greenwich. In fact, it is 77° 33′ behind the amount of rotation at Greenwich. Therefore, the local hour angle is equal to the *GHA* (279° 04.3′) minus the longitude (77° 33′) or 201° 31.3′.

*c.* We now have the polar distance *P* which is 60.5′ and the *LHA* which is 201° 31.3′. The altitude of the star was measured as 33° 34′ above horizontal. Using the formula:

$$\text{Bearing} = \frac{P \sin LHA}{\cos h}$$

$$P = 60.5'$$

$$LHA = 201^\circ\ 31.3'$$

$$h = 33^\circ\ 34'$$

Natural sine of 201° 31.3′ = sine of 21° 31.3′ = 0.367

Natural cos of 33° 34′ = 0.833

$$\text{Bearing} = \frac{60.5 \times 0.367}{0.833} = 26.6'$$

*d.* The *LHA* was more than 180° indicating that the star had gone from the observer's meridian toward the west and passed the lower half of the observer's meridian and gone 21° 31.3′ beyond. Therefore, the star was 26.6′ east of north. The angle measured from the star to the mark was 65° 45′ (Mark right (east) of star). Therefore, the azimuth of the mark is 65° 45′ + 26.6′ = 66° 11.6′ true azimuth. Note that if the latitude (34° 30′) had been used instead of the measured altitude, the cosine of *h* would have been 0.824 and the computed bearing would have been 26.9′ instead of 26.6′. Thus, if the vertical circle is not reliable or if there is none on the transit, the latitude of the position may be taken from a map and this value used instead of a measured altitude of Polaris. The polar distance must always be in terms of minutes and the bearing determined will then be in terms of minutes. This method gives an accuracy of about 1 minute of angle.

## Section IV. ANY STAR—EQUAL ALTITUDES

### 194. General

The equal altitudes method is especially applicable in the Southern

and sight as in the first operation. It is not necessary to either take the time or read the angle when sighting at the mark.

*e.* Loosen the upper motion, turn to the star, read and record the time and the *A* vernier reading, and altitude. This completes a single set of readings. At least two more sets are taken if there is any doubt about any one set.

## 191. Example of field notes

The table on page 166 shows an example of the proper method of recording the field notes for a star observation:

## 192. Computation

The computations for determining true north by the Polaris at any hour method is based on the formula:

$$\text{Bearing} = \frac{P \sin LHA}{\cos h}$$

Where $P$ = Polar distance (determined from almanac)
$LHA$ = Local hour angle (computed from time)
$h$ = Altitude of star (measured with transit)

The Greenwich hour angle of Polaris for 0 hour Greenwich Civil Time is determined from the American Nautical Almanac and this Greenwich hour angle (*GHA*) is changed to local hour angle (*LHA*) by correcting the *GHA* for time of observation and longitude of the position as in paragraph 193.

## 193. Example

An observation was made on Polaris at Camp Davis, N. C. (data taken from first set in par. 191).

Date: 15 September 1943.

Time: $16^h\ 46^m\ 40^s - 10^s = 16^h\ 46^m\ 30^s$ Eastern War Time = $20^h\ 46^m\ 30^s$ Greenwich Civil Time.

Latitude: 34° 30′ north.

Longitude: 77° 33′ west.

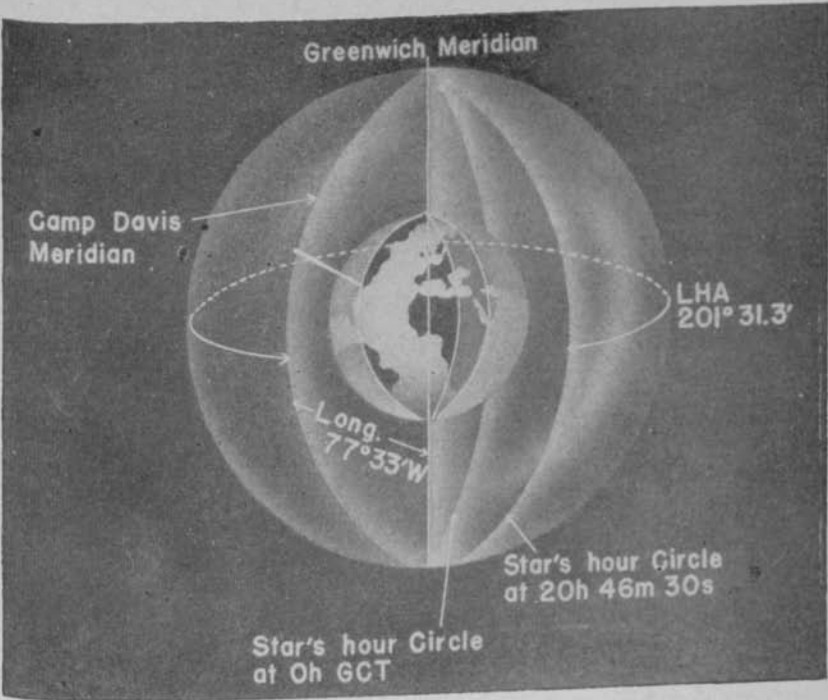
Angle: Star to Mark 65° 45′ Mark right (East).

Altitude of star: 33° 34′ (measured with transit).

Polar distance of Polaris 15 September 1943 by almanac = 90° −88° 59′ 33″ = 1° 00.5′ = 60.5′.

*a.* To determine *LHA*.

| | |
|---|---|
| *GHA* of Polaris 15 Sept 1943 at $0^h$ GCT | = 326° 35.6′ (by almanac) |
| Correction for 20 hours 46 minutes (Determined from tables of correction following star tables in almanac) | = 312° 21.2′ |
| Correction for 30 seconds | = 7.5′ |
| *GHA* at time of observation | = 639° 04.3′ |
| *GHA* −360° = 639° 04.3′ −360° | = 279° 04.3′ |
| Longitude of position | = 77° 33.0′ west (subtract) |
| *LHA* at time of observation | = 201° 31.3′ |



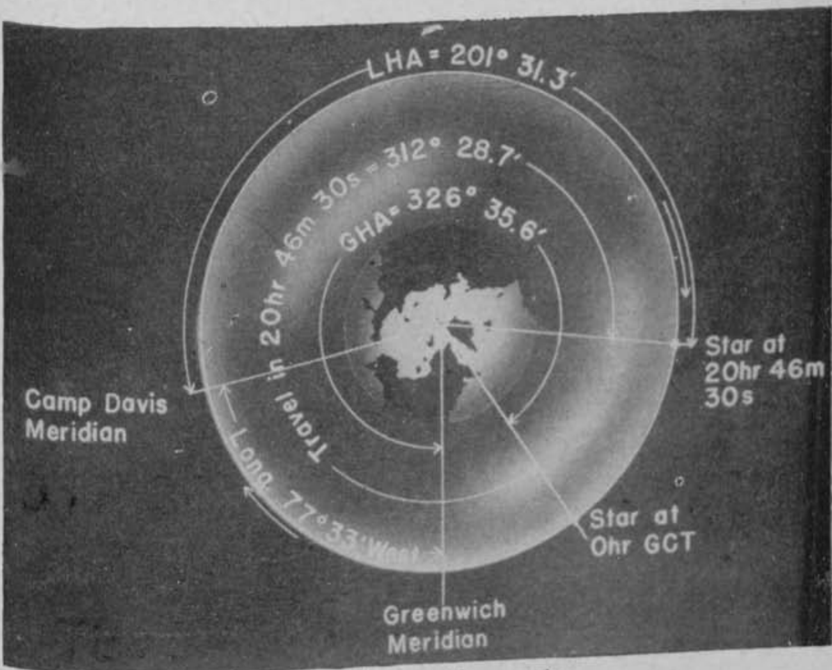




*Figure 125. Local hour angle.*

Hemisphere because there is no bright star in the vicinity of the South Celestial Pole similar to Polaris in the Northern Hemisphere. The closest circumpolar stars in the Southern Hemisphere are about 20° or more from the celestial pole. The orbits of these stars are so large that a different method must be used from that used for Polaris. The equal altitudes method depends on observing a star when it is at the same altitude on each side of the observer's meridian. In figure 128, the south celestial pole is at *P* and the orbit of star is along the arc *AB*. *A* is the location of the star at the time of the first observation. At the time of the first observation the altitude *h* of the star and the horizontal angle from a mark to the star is measured. When the star has moved so that it has the same altitude at *B* as it had at *A*, the horizontal angle from the same mark as used in the first observation to the star is measured. One half of the difference between the two horizontal angles will be the angle from the star to the horizontal projection of the celestial pole thereby defining a line from the observer to the point *N* which will

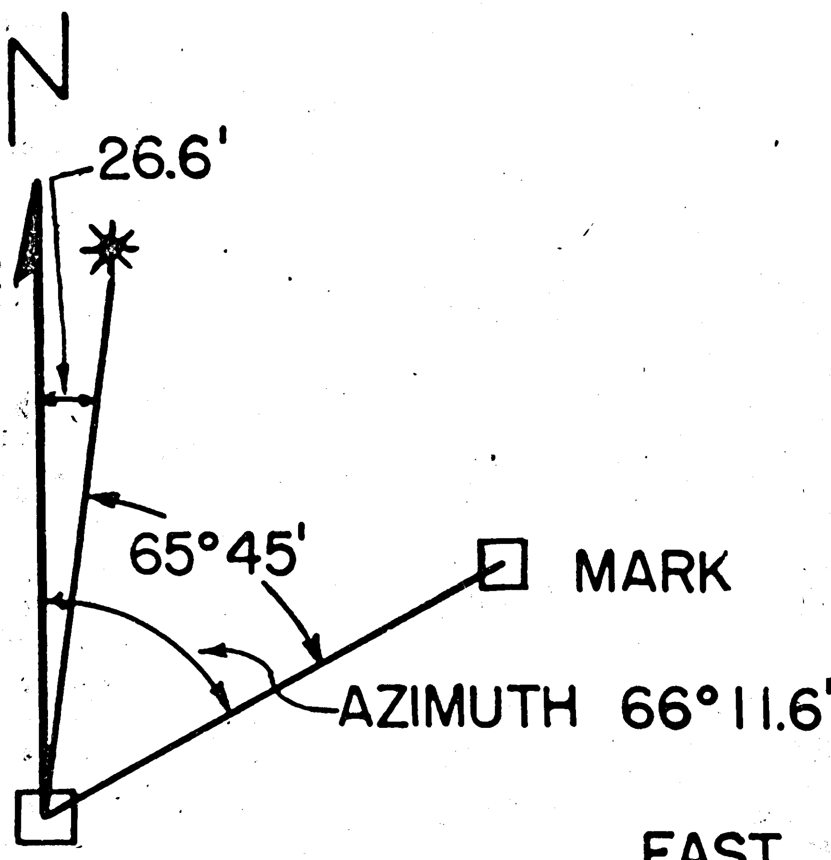



*Figure 126. Diagram of angles.*

be true north or south, depending on which hemisphere the observer is stationed. The method does not require the use of an almanac, precise time or astronomical computations. However, the two observations must be made at least 6 or 8 hours apart and a star must be selected that will be in a position to be observed before daylight again makes observation impossible.

## 195. Procedure

*a.* LEVELING. The transit is set up over the point from which an azimuth is to be determined. An azimuth mark is set up so that the angle from the mark to the star may be measured. A flashlight mounted exactly over a stake makes a convenient mark. Next, select a star that is roughly 3 or 4 hours from lower culmination (directly below the pole) and one that may easily be identified 6 or 8 hours later. One of the stars in the Big Dipper or Cassiopeia is convenient in the Northern Hemisphere. In the Southern Hemisphere, Achernar, Canopus, Acrux, or Rigel Kentaurus are most convenient. As the altitude of the star is the most important reading to be made in this method, it is advisable to level the transit very precisely. This is done by means of the telescope level. Level the transit by means of the plate bubbles in the customary manner, then level the telescope by centering the telescope level bubble with the telescope parallel to the line between two diagonally opposite leveling screws. Rotate the telescope 180°. If the bubble does not remain centered, bring it halfway back by means of the slow motion knob of the vertical motion and complete the centering of the bubble by the leveling screws directly below the telescope. Turn the telescope so that it is parallel to the other set of leveling screws and again center the telescope bubble by means of the vertical slow motion knob. Rotate

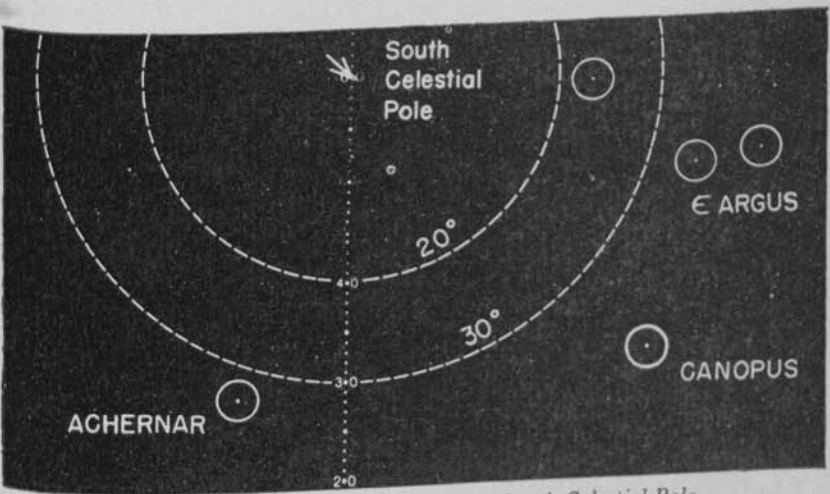



*Figure 127. Photograph of stars near South Celestial Pole.*

the telescope 180° about the vertical axis and recenter the telescope bubble by a combination of the vertical motion and leveling screws as before.

*b.* Angle measurement. Sight the telescope at the azimuth mark with the horizontal scale set at 0° and with the upper and lower motions clamped. Release the upper motion and sight upon the selected star. The star should be bisected by both cross hairs at the same time. The operation of the telescope may be simplified by dropping the horizontal cross hairs below the star and tracking it in azimuth by the slow motion of the upper horizontal plate until the star is bisected by the horizontal cross hair. The motion is then stopped and the altitude and horizontal angle read and recorded. Several successive readings may be taken and recorded to allow an average to be made. This will give a more precise determination. The transit is then removed from the position and placed in a safe place until the second observation is to be made.

*c.* Second observation. When the star has passed the observer's meridian and is approaching the same altitude on the other side of its orbit (6 or 8 hours later), the observer prepares for the second observation. Set the transit up over the same point as before and level the transit precisely as previously described. Set the horizontal scale to zero and sight at the same azimuth mark as before and clamp the lower motion. Release the upper plate and set the lowest altitude previously read on the vertical scale. Turn the telescope toward the same star used in the first set of observations and track it in azimuth until the star is bisected by the horizontal cross hair. Read and record the horizontal scale reading. This reading should be recorded opposite the horizontal reading made on the first observation with that altitude. The vertical scale is then set at the next higher altitude recorded and the star tracked

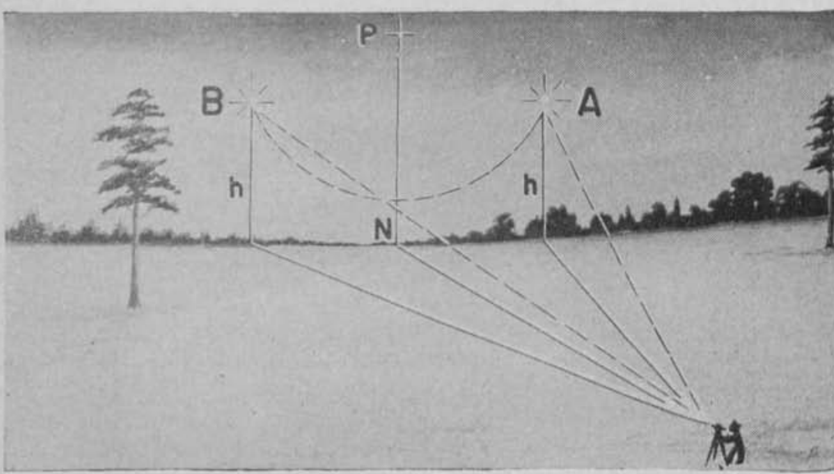



*Figure 128. Diagram of equal altitudes.*

and angle read in the same manner. When readings have been taken at all altitudes measured on the first observation, the angle from the azimuth mark to true south (or north depending on the hemisphere) is computed. The angle from the azimuth mark to true south (or north) will be equal to the sum of the angular measurements divided by the number of angles measured. For example if only two angles were measured, one when the star was right of the pole and one when it was left of the pole, the sum of the two horizontal angles divided by two would give the average of the two which would be the angle from the azimuth mark to the pole. If one angle was right of the azimuth mark and one left the left angles should be given a minus sign and the algebraic sum divided by the number of horizontal angles read. Figure 129 is an excerpt from a field notebook showing the manner of recording data and of computing the angle of true south.

### 196. Summary

This method eliminates any error due to index correction in the transit and any refraction error. The computations are purely arithmetic, and a knowledge of astronomy or possession of an almanac or precise time are unnecessary. With careful instrumental work, the direction determined should be accurate within a minute of angle. The method is inconvenient, as it requires set-ups 6 or 8 hours apart, and clouds may make it impossible to complete the observations. With personnel unfamiliar with celestial observations, or when time is not accurate, or when an almanac is not available, this method is very valuable.

## Section V. ANY STAR—ALTITUDE METHOD

### 197. General

The reconnaissance officer in the past has been in the habit of depending on observations taken on Polaris because it is a star easily found and readily recognized. There are several disadvantages in permitting such a habit to be formed, one of which is that in global war, there is no assurance that the star will be visible from the theater of operations. If a system is based on one star, the reconnaissance officer is unlikely to be familiar with methods of observation on other stars and loss of the one star may cause the system to fail. The altitude method may be used in any part of the world and is usable with any visible star for which the declination is known. It therefore requires accurate star identification and an almanac or tabulation of declinations. Table III, appendix I,

has been made up to take the place of a Nautical Almanac for use in the altitude method of observation. The Table gives the right ascension and declination of 23 principal navigational stars for the years 1944 to 1948. Chapter 14 presents methods of star identification for the principal stars. With these data, the reconnaissance officer can use the altitude method of observation and needs no additional data other than a map or knowledge of approximate latitude.

## 198. Selection of star

The altitude method of observation determines the azimuth of the star from its altitude. Therefore, a star is selected that is changing in altitude faster than in azimuth, so that an error in altitude makes a smaller error in azimuth. This condition may be met by selecting a star near the prime vertical of the observer. The prime vertical for an observer in North America is shown in figure 130. The prime vertical is the vertical circle whose plane is perpendicular to the plane of the observer's meridian. It cuts the observer's horizon in the east and west points. Therefore, a star almost east or west of the observer is better for observation by the altitude method. The apparent altitude of a star is not the same as the true altitude of a star because of refraction. Refraction causes a celestial body to appear higher than its true position. (See fig. 131.) It is necessary to make a correction for refraction on altitudes measured for use with the altitude method. Refraction corrections become uncertain below 20° altitude so that the observations should be made on stars higher than 20° above the horizontal. Instrumental errors are introduced when making observations on stars higher than 45°. Therefore the selected star should be somewhere between 20° and 45° above horizontal and east or west of the position. The

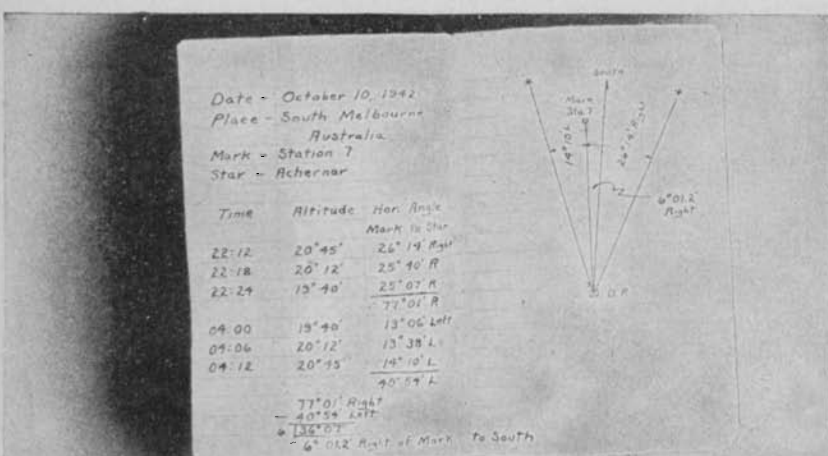



Figure 129. Excerpt from notebook.

limitation of position of stars for observation shown in figure 132 should not be considered as limiting time for observation. A sufficient number of stars are available to have at least one in a favorable position at all times.

## 199. Procedure

Set the transit up at the station from which an azimuth is desired. Level the instrument precisely in the same manner as described in section IV for the equal altitudes method. Set up an azimuth mark from which the horizontal angles are to be measured. Set the horizontal scale to 0°, sight on the azimuth mark and clamp the lower motion. Release the upper motion and sight on the selected star. Bisect the star by both the horizontal and vertical cross hairs. ~~When the star has been~~ bisected percisely by both cross hairs at the same ~~time,~~ read and record the reading of the ~~vertical and~~ horizontal scales. Several observations ~~should be made and the average of the results used to increase accuracy.~~

## 200. Computation

The altitude method is based on two formulae, one for the Northern Hemisphere and one for the Southern Hemisphere.

Northern Hemisphere:

$$\text{Cos } Z = \frac{\sin d - \sin \Phi \sin h}{\cos \Phi \cos h}$$

Southern Hemisphere:

$$\text{Cos } Z = \frac{\sin \Phi \sin h - \sin d}{\cos \Phi \cos h}$$

$Z$ = bearing from elevated pole (North Pole in Northern Hemisphere, South Pole in Southern Hemisphere).

$\Phi$ = Latitude (may be determined from map).

$h$ = altitude (measured by transit).

$d$ = declination of star (from table III, app. I).

The latitude ($\Phi$) and the declination ($d$) should be determined to the closest tenth of a minute for precise results.

## 201. Example

An observation was made on the star Sirius ($\alpha$ Canis Major) on 2 September 1944. The observed altitude was measured to be 39° 09′. The angle mark to star was 18° 52′ star right of azimuth mark. The latitude of the position of the observer was 31° 45′ 10″ south and longitude 29° 46′ 30″ east. The measured altitude must be corrected for refraction. The refraction correction, obtained from Table XXI, TM 5–236, is determined as 1′ 11″ or 1.2′.

39° 09′ — 1.2′ = 39° 07.8′ (The refraction correction is always subtracted).

The following data are now known:

Corrected altitude ($h$) = 39° 07.8′

Latitude ($\Phi$) = —31° 45′ 10″ (from map)

Declination ($d$) = —16° 38.2′ (from table III, app. I).

The formula is $\cos Z = \dfrac{\sin \Phi \sin h - \sin d}{\cos \Phi \cos h}$

| | | |
|---|---|---|
| Log sin $\Phi$ = log sin 31° 45.2′ | | = 9.72120 |
| log sin $h$ = log sin 39° 07.8′ | | = 9.80009 |
| Sum logs | | = 9.52129 |
| Value (natural) | | = 0.33212 |
| natural sin $d$ = sin —16° 38.2′ | | = 0.28630 |
| Value | | = 0.04582 |
| log 0.04582 = | 8.66106 | |
| log cos $\Phi$ = log cos 31° 45.2′ | | = 9.92958 |
| log cos $h$ = log cos 39° 07.8′ | | = 9.88970 |
| | —9.81928 | 9.81928 |
| log cos $Z$ = | 8.84178 | |
| $Z$ = 86° 01.0′ | | |

The value of $Z$ is determined to be 86° 01.0′ however, the angle 93° 59.0′ has the same logarithm. Therefore $Z$ = 86° 01.0′ or 93° 59.0′. A comparison of declination of the star and latitude of the observer's position will indicate whether the bearing angle is over or under 90°. (See fig. 133.) The declination of the star (Sirius) is —16° 38.2′ and the latitude of the observer's position is —35° 45′ 10″. Therefore, the observer's zenith has a position on the celestial sphere corresponding to

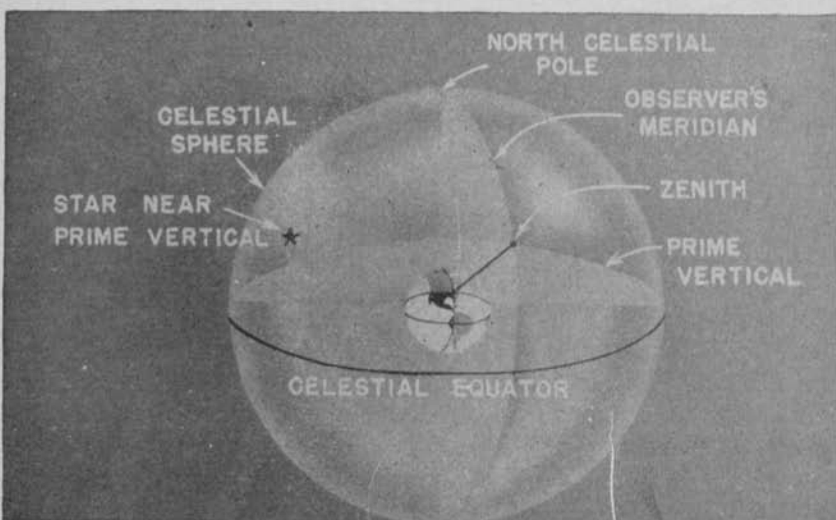



*Figure 130. Star near prime vertical.*

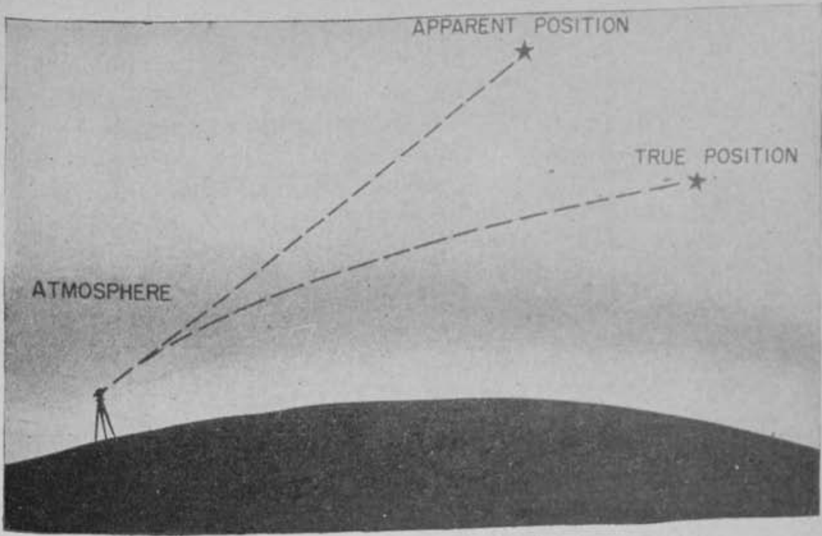



*Figure 131. Effect of refraction.*

a declination of —35° 45′ 10″. Therefore the star (Sirius) is closer to the celestial equator than is the observer's zenith. The star's bearing Z will then be toward the equator and away from the pole. Therefore, the bearing angle is 93° 59.0′ rather than 86° 01.0′. The star was rising at the time of observation, therefore it was in the east. The bearing is computed from the elevated pole. The position of the observer was in south latitude so bearing is from the south pole. Bearing is south 93° 59′ east. A comparison of declination and latitude will always correctly indicate the bearing as being under 90° when the declination of a star is *more* than the latitude of the position. However, when the

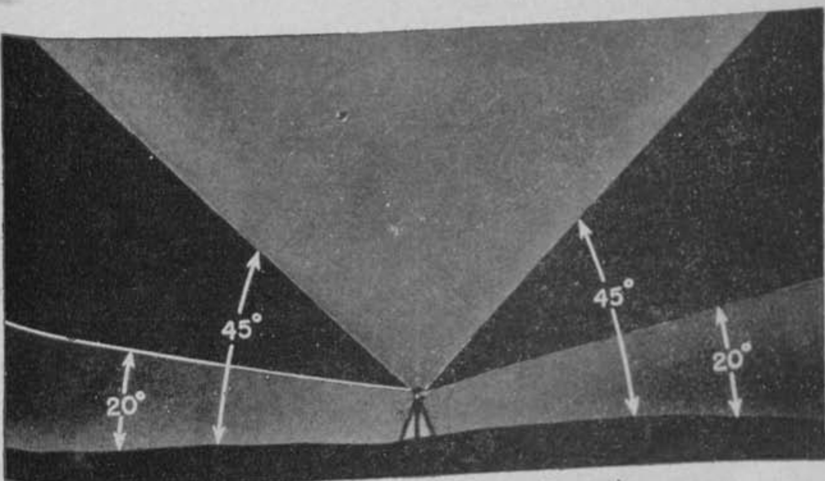



*Figure 132. Limitations of area for observation.*

declination of a star is *less* than the latitude of the position, and both are in the same hemisphere, the altitude of the star determines the bearing in some cases. The following table lists the lowest altitude at which a bearing will be *greater* than 90° for various combinations of latitude and declination of the same sign. In other words, an altitude lower than one listed for a given declination and latitude will yield a bearing *less* than 90° from the elevated pole.

Tabulation of the lowest altitude of star in degrees, at which a bearing will be greater than 90°, when declination of star is less than latitude of position.

| LATITUDE IN DEGREES | DECLINATION IN DEGREES | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 |
| 2 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | | | | | | | | | | | | |
| 4 | 0 | 30 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | | | | | | | | | | | | |
| 6 | 0 | 19 | 42 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | | | | | | | | | | | | |
| 8 | 0 | 14 | 30 | 49 | 90 | 90 | 90 | 90 | 90 | 90 | | | | | | | | | | | | |
| 10 | 0 | 11 | 24 | 37 | 53 | 90 | 90 | 90 | 90 | 90 | | | | | | | | | | | | |
| 12 | 0 | 10 | 19 | 30 | 42 | 56 | 90 | 90 | 90 | 90 | | | | | | | | | | | | |
| 14 | 0 | 8 | 17 | 26 | 35 | 46 | 59 | 90 | 90 | 90 | | | | | | | | | | | | |
| 16 | 0 | 7 | 15 | 22 | 30 | 39 | 49 | 61 | 90 | 90 | | | | | | | | | | | | |
| 18 | 0 | 7 | 13 | 20 | 27 | 34 | 42 | 51 | 63 | 90 | 90 | | | | | | | | | | | |
| 20 | 0 | 6 | 12 | 18 | 24 | 30 | 37 | 45 | 54 | 65 | 90 | 90 | | | | | | | | | | |
| 22 | 0 | 0 | 11 | 16 | 22 | 28 | 34 | 40 | 47 | 56 | 66 | 90 | 90 | | | | | | | | | |
| 24 | 0 | 0 | 10 | 15 | 20 | 25 | 31 | 36 | 42 | 49 | 57 | 67 | 90 | 90 | | | | | | | | |
| 26 | 0 | 0 | 9 | 14 | 18 | 23 | 28 | 33 | 39 | 45 | 51 | 59 | 68 | 90 | 90 | | | | | | | |
| 28 | 0 | 0 | 9 | 13 | 17 | 22 | 26 | 31 | 36 | 41 | 47 | 53 | 60 | 69 | 90 | 90 | | | | | | |
| 30 | 0 | 0 | 8 | 12 | 16 | 20 | 25 | 29 | 33 | 38 | 43 | 49 | 54 | 61 | 70 | 90 | 90 | | | | | |
| 32 | 0 | 0 | 7 | 12 | 15 | 19 | 23 | 27 | 31 | 36 | 40 | 45 | 50 | 56 | 62 | 70 | 90 | | | | | |
| 34 | 0 | 0 | 7 | 11 | 14 | 18 | 22 | 25 | 30 | 33 | 38 | 42 | 46 | 52 | 57 | 63 | 90 | 90 | | | | |
| 36 | 0 | 0 | 7 | 10 | 14 | 17 | 21 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 53 | 58 | 64 | 72 | 90 | | | |
| 38 | 0 | 0 | 6 | 10 | 13 | 16 | 20 | 23 | 26 | 30 | 34 | 38 | 41 | 45 | 49 | 54 | 59 | 65 | 73 | 90 | | |
| 40 | 0 | 0 | 6 | 9 | 13 | 16 | 19 | 22 | 25 | 29 | 32 | 35 | 39 | 43 | 47 | 51 | 55 | 60 | 66 | 73 | 90 | |
| 42 | 0 | 0 | 5 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 34 | 37 | 41 | 44 | 48 | 52 | 57 | 61 | 66 | 74 | 90 |
| 44 | 0 | 0 | 0 | 9 | 12 | 14 | 17 | 20 | 23 | 26 | 29 | 33 | 36 | 39 | 42 | 46 | 50 | 53 | 58 | 62 | 68 | 75 |
| 46 | 0 | 0 | 0 | 8 | 11 | 14 | 16 | 20 | 23 | 25 | 28 | 31 | 34 | 38 | 41 | 44 | 47 | 51 | 55 | 59 | 63 | 68 |
| 48 | 0 | 0 | 0 | 8 | 11 | 13 | 16 | 19 | 22 | 25 | 27 | 30 | 33 | 36 | 39 | 42 | 45 | 49 | 52 | 56 | 60 | 64 |
| 50 | 0 | 0 | 0 | 8 | 10 | 13 | 16 | 18 | 21 | 24 | 26 | 29 | 32 | 34 | 38 | 41 | 44 | 46 | 50 | 53 | 58 | 60 |
| 52 | 0 | 0 | 0 | 8 | 10 | 13 | 15 | 18 | 21 | 23 | 25 | 28 | 31 | 33 | 36 | 39 | 42 | 44 | 47 | 51 | 55 | 57 |
| 54 | 0 | 0 | 0 | 8 | 10 | 12 | 15 | 17 | 20 | 22 | 25 | 28 | 30 | 32 | 34 | 38 | 41 | 42 | 45 | 49 | 52 | 53 |
| 56 | 0 | 0 | 0 | 7 | 10 | 12 | 15 | 17 | 19 | 22 | 24 | 27 | 29 | 30 | 33 | 36 | 39 | 41 | 44 | 46 | 50 | 51 |
| 58 | 0 | 0 | 0 | 7 | 9 | 12 | 14 | 17 | 19 | 21 | 23 | 26 | 29 | 29 | 31 | 34 | 38 | 39 | 42 | 44 | 47 | 49 |
| 60 | 0 | 0 | 0 | 7 | 9 | 11 | 14 | 16 | 19 | 21 | 23 | 25 | 28 | 29 | 30 | 32 | 36 | 38 | 41 | 42 | 44 | 46 |

The horizontal angle measured was 18° 52′ and the star was right of the azimuth mark. The angles are shown in figure 136.

The azimuth mark is then at a bearing of 93° 59′ + 18° 52′ east of south or S 112° 51′ E. The azimuth of the mark is then 247° 09′ from south or 67° 09′ from north.

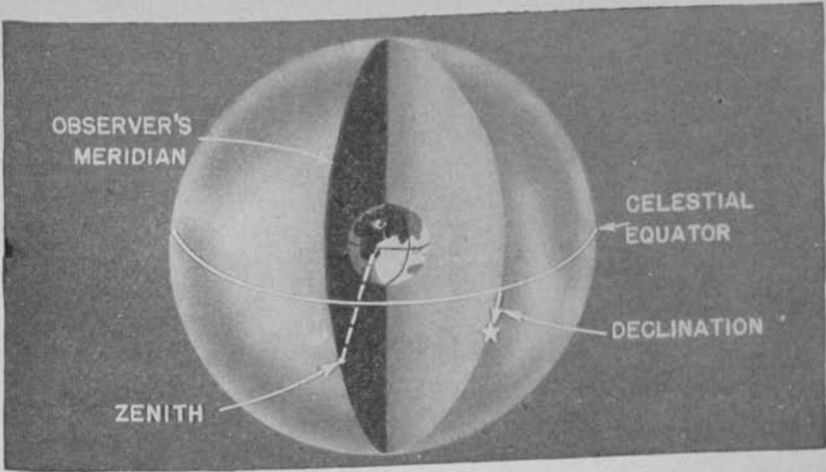



*Figure 133. Comparison of observer's zenith and star position.*

## 202. Summary

This method does not require precise time, in fact no time is used as the date is sufficient to determine the declination of the star. The computations do require the use of both natural and logarithmic functions of angles for simple solution or the use of natural functions and long hand multiplication and division. However, the computations should not be difficult for personnel having a basis of elementary trigonometry. The accuracy of this method depends upon the accuracy of the instru-

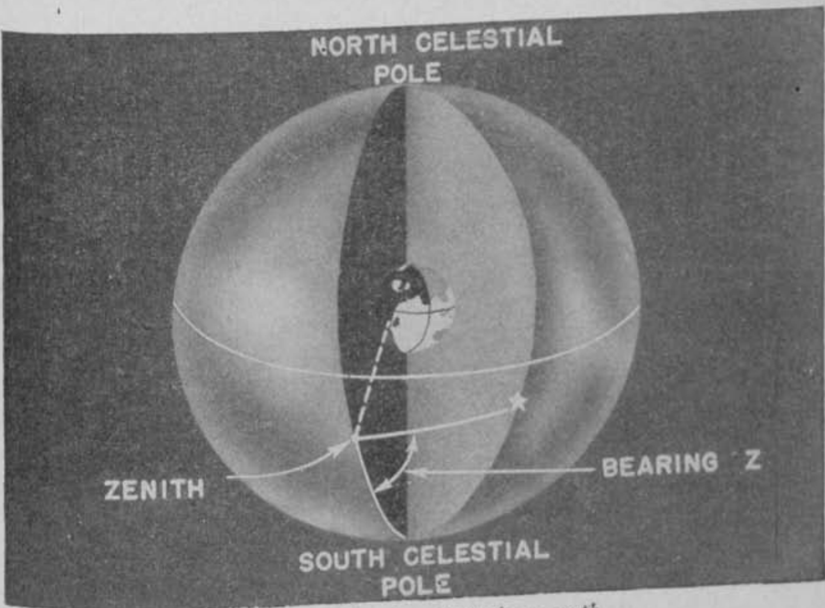



*Figure 134. Bearing of star from south.*

ment in measuring vertical angles and the competence of the using personnel. With an instrument in good adjustment and an observer with ordinary skill, results should be correct within 1 minute of angle. This same method of observation may be used with the formula presented in section II, chapter 13. The two formulae are presented to enable a reconnaissance officer to select the formula more readily computed by him.

## Section VI. ANY STAR—HOUR ANGLE METHOD

### 203. General

The simplest method of computation for observations by the hour angle method is by use of the Ageton Formulae. The Ageton Formulae allow the solution of an observation by logarithmic secants and cosecants multiplied by 100,000 so that the functions of most angles are in whole numbers. The Ageton tables are given in table II, TM 5–236, and are actually tables of logarithmic secants and cosecants multiplied by 100,000. If a standard form is used it is possible to solve a celestial observation without knowing the Ageton formulas or understanding their derivation. In order to simplify the solution, and also to keep the reconnaissance officer from filling his mind with nonessential information, the formulae and their derivation are not presented in this manual. The complete discussion on theory and derivation is included in the Hydrographic Office Publication No. 211, Dead Reckoning Altitude and Azimuth table by Ageton, for those officers interested in the theory of the formulae. The solution by the Ageton method requires the local

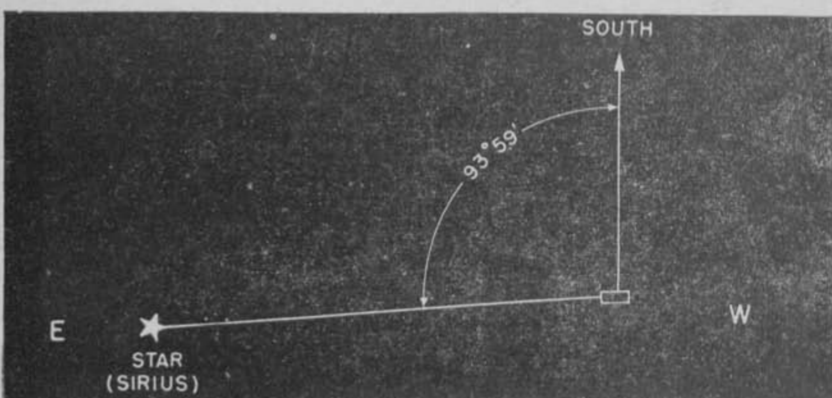



*Figure 135. Diagram of bearing of star.*

hour angle of the star thereby requiring a knowledge of precise time. The standard form sheet includes all mechanical rules for solving a celestial observation; however, one sample problem is presented in detail to amplify the information given on the standard form sheet.

## 204. Theory

The watch to be used in the observation is checked with a chronometer or by radio time signals to determine the error of the watch to the closest second. In setting a watch it is advisable to set the minute hand so that it reads an even minute when the second hand reads 60. No attempt should be made to set the second hand to read the exact time as a correction to the watch time can be easily made. The latitude and longitude of the position are determined to the closest 1/10 minute for precise results. The horizontal angle from the azimuth mark to the star is measured and the exact time at which the angle was measured is recorded along with the horizontal angle. The altitude of the star is unnecessary by this method so that the vertical angle to the star is not measured. The time of observation is changed to Greenwich Civil Time and the Greenwich hour angle is determined for that time, from the Nautical Almanac. A correction for longitude is applied to the Greenwich hour angle to determine the local hour angle. The local hour angle is entered on the form along with the declination of the star, determined from the almanac. The bearing of the star is determined by use of the Ageton tables, table LI, TM 5–236, and this bearing is combined with the angle to the azimuth mark from the star to determine the true azimuth of the mark.

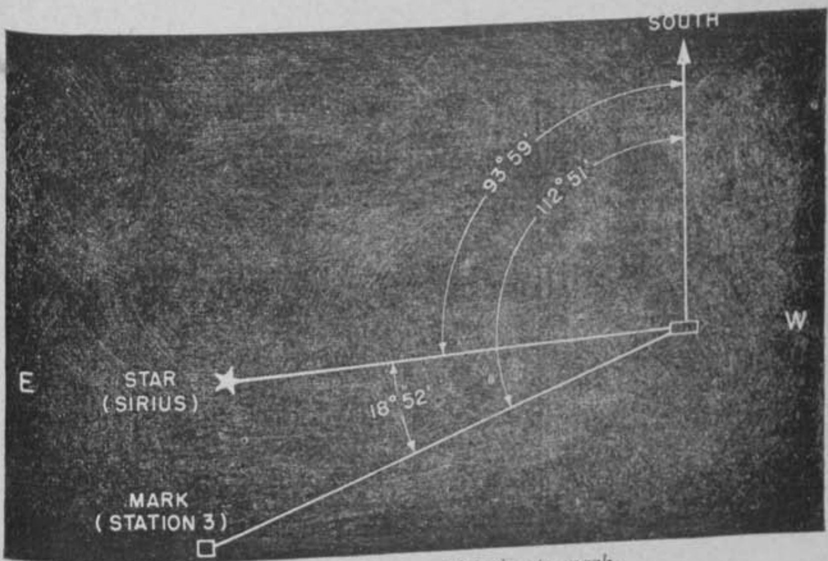



*Figure 136. Diagram of bearing to mark.*

# AZIMUTH DETERMINATION

(AGETON METHOD)

| | | | | | |
|---|---|---|---|---|---|
| STATION | ______ | | | DATE | ______ |
| S | ______ | LONGITUDE | ______ | PLACE | ______ |
| MARK | ______ | LATITUDE | ______ | NAME | ______ |
| | | WATCH | ______ | | |

| HOUR ANGLES | 1st Set | | | 2nd Set | | | 3rd Set | | |
|---|---|---|---|---|---|---|---|---|---|
| Time of Observation (0–24 hrs) | hr | min | sec | hr | min | sec | hr | min | sec |
| Watch Correction | | | | | | | | | |
| Corrected Time of Observation | | | | | | | | | |
| Time Difference Greenwich | | | | | | | | | |
| Greenwich Civil Time of Observation | | | | | | | | | |
| 1-Greenwich H.A. (Almanac) | | | | | | | | | |
| 2-Correction (hrs. & mins) | | | | | | | | | |
| 3-Correction (seconds) | | | | | | | | | |
| 4-G.H.A. (Time of Observation) sum of 1, 2, & 3 | | | | | | | | | |
| 5-Longitude W(-) E(+) | | | | | | | | | |
| 6-Algebraic Sum (4 & 5) subtract 360 if over 360° | | | | | | | | | |
| 7-L.H.A. (-)or(+) if over 180° use L.H.A. - 360° | | | | | | | | | |

**RULES**:-

1- Give K same sign as declination (d).
2- Combine K and $\phi$ (K~$\phi$). Add arithmetically if different signs. Subtract if same signs.
3- Z is bearing from elevated pole (North pole in northern hemisphere, South pole in southern hemisphere) in direction of celestial body. (Indicated by L.H.A.)

| ANGLE | ADD | SUBTRACT | ADD | SUBTRACT |
|---|---|---|---|---|
| L.H.A. | A | | | |
| d | B | A | | |
| | A | B | B | A |
| | K= | A | | |
| | $\phi$= | K~$\phi$= | B | |
| | | h= | A | B |
| L.H.A | A | | $Z_1$= | A |
| d | B | A | | |
| | A | B | B | A |
| | K= | A | | |
| | $\phi$= | K~$\phi$= | B | |
| | | h= | A | B |
| L.H.A. | A | | $Z_2$= | A |
| d | B | A | | |
| | A | B | B | A |
| | K= | A | | |
| | $\phi$= | K~$\phi$= | B | |
| | | h= | A | B |
| | | | $Z_3$= | A |

**GRID AZIMUTH**: Bearing is WEST if L.H.A. is (+), EAST if L.H.A. is (-).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bearing (Z) East or West | | | | | | | | |
| True Azimuth to S | | | | | | | | |
| Average Angle to Mark | | | | | | | | |
| True Azimuth to Mark | | | | | | | | |
| Mean True Azimuth to Mark | | | | | | | | |
| Grid Divergence | | | | | | | | |
| Grid Azimuth to Mark | | | | | | | | |

*Figure 137. Standard Ageton form.*

## AZIMUTH DETERMINATION

(AGETON METHOD)

STATION S MARK: PROCYON

LONGITUDE: +44° 08.4'

LATITUDE: +17° 10.2'

WATCH: FAST 1 MIN. 14 SEC.

DATE: NOV. 25, 1942

PLACE:

NAME:

| HOUR ANGLES | 1st Set hr | min | sec | 2nd Set hr | min | sec | 3rd Set hr | min | sec |
|---|---|---|---|---|---|---|---|---|---|
| Time of Observation (0–24 hrs.) | 2 hr 3 | 30 | 45 | | | | | | |
| Watch Correction — | | –1 | 14 | | | | | | |
| Corrected Time of Observation | 23 | 29 | 31 | | | | | | |
| Time Difference Greenwich | –3 | 00 | 00 | | | | | | |
| Greenwich Civil Time of Observation | 20 | 29 | 31 | | | | | | |
| 1-Greenwich H.A. (Almanac) | | | | | | | | | |
| 2-Correction (hrs. & mins.) | | | | | | | | | |
| 3-Correction (seconds) | | | | | | | | | |
| 4-G.H.A. (Time of Observation) sum of 1, 2, & 3 | | | | | | | | | |
| 5-Longitude W(–) E(+) | | | | | | | | | |
| 6-Algebraic Sum (4 & 5) subtract 360 if over 360° | | | | | | | | | |
| 7-L.H.A. (–) or (+) if over 180° use L.H.A. – 360° | | | | | | | | | |

RULES:-

1- Give K same sign as declination (d).

2- Combine K and $\phi$ (K–$\phi$) Add arithmetically if different signs. Subtract if same signs.

3- Z is bearing from elevated pole (North pole in northern hemisphere, South pole in southern hemisphere) in direction of celestial body. (Indicated by L.H.A.)

*Figure 138. Ageton form complete to Greenwich Civil Time.*

## 205. Procedure

Before making an observation, check the timekeeper's watch with some source of precise time and determine the correction to be applied

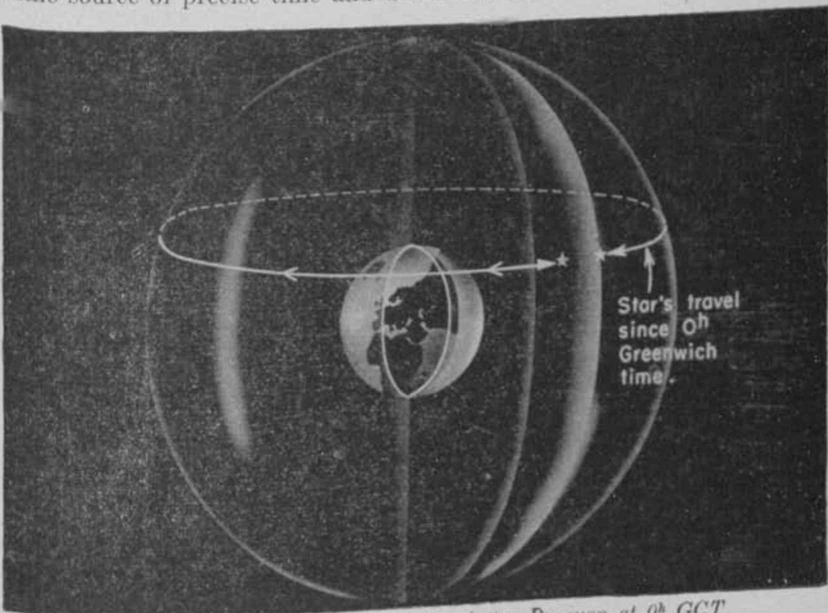



*Figure 139. Greenwich hour angle of star Procyon at $0^h$ GCT.*

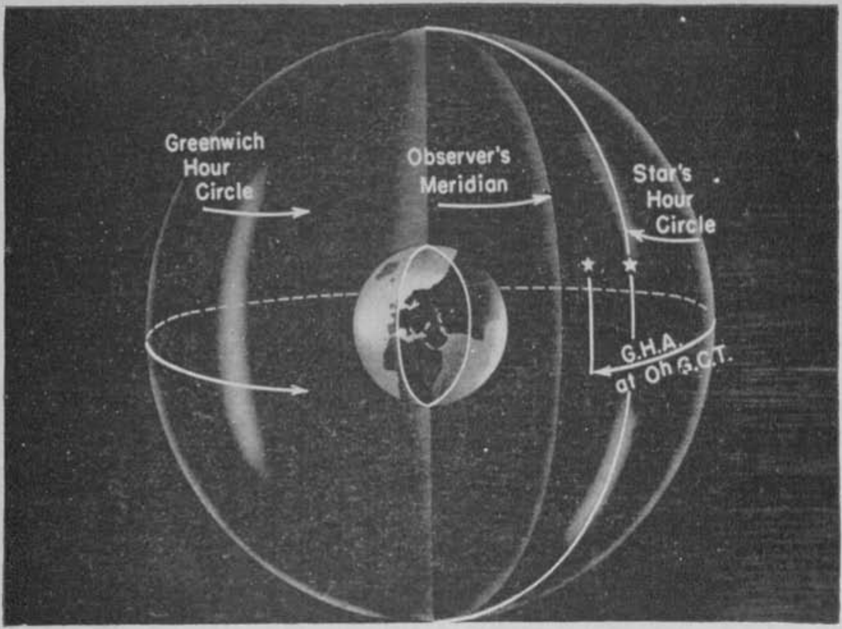



*Figure 140. Travel of star Procyon since $0^h$ GCT.*

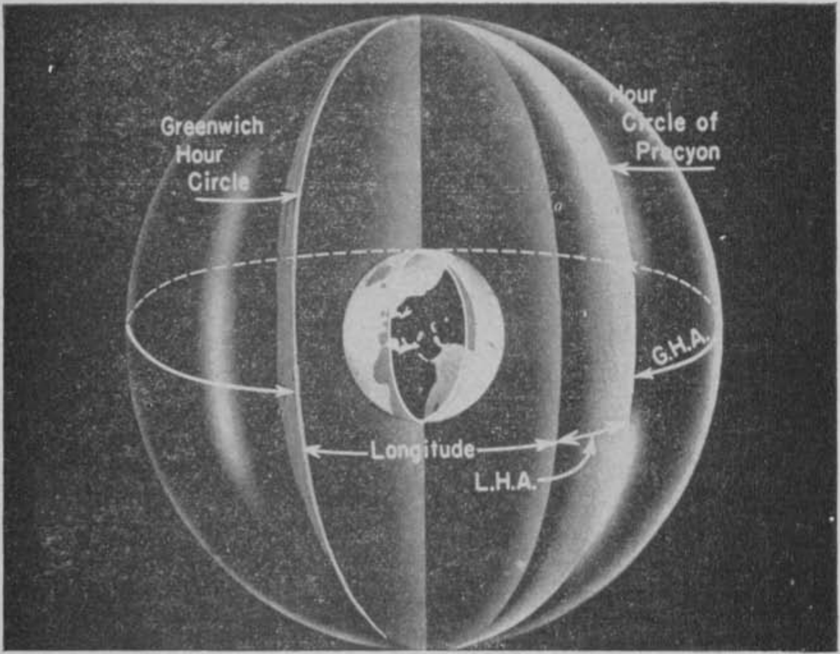



*Figure 141. Local hour angle.*

to derive a standard time. Establish an azimuth mark. Select a star that is in a favorable position that can positively be identified. A star favorable for use in the hour angle method should be changing very slowly in azimuth and whose altitude is not too great for accurate pointing. A star east or west of the position and lower than 45° in altitude is ideal. Set up the transit at the point from which a direction is to be determined. Set the horizontal scale to zero, sight on the azimuth mark and clamp the lower motion. Release the upper motion and sight on the star with the vertical cross hair. When the vertical cross hair bisects the star, call "Time" and cease tracking the star. The time-keeper notes the exact time and enters it in the notebook. Read the horizontal angle measured to the star and record it in the notebook along with the time of that observation. Plunge the telescope and turn onto the mark with the lower motion. Again turn onto the star and when the star is bisected by the vertical cross hair again call "Time" and stop the horizontal movement of the telescope at the same time. The new time and new horizontal angle are combined with the first time and angle to give an average time and angle for the first set. Three such sets are always made, to serve as a check for erroneous results. This completes the field work for the observation.

## 206. Computation

The standard Ageton form will be used for computations. (See fig. 137.) The following data were known prior to the observation:

**AZIMUTH DETERMINATION**
(AGETON METHOD)

DATE NOV. 25, 1942
PLACE
NAME

STATION
S PROCYON
MARK

LONGITUDE +44° 08.4'
LATITUDE +17° 10.2'
WATCH FAST 1 MIN. 14 SEC.

| HOUR ANGLES | 1st Set hr | min | sec | 2nd Set hr | min | sec | 3rd Set hr | min | sec |
|---|---|---|---|---|---|---|---|---|---|
| Time of Observation (0–24 hrs.) | 23 | 30 | 45 | | | | | | |
| Watch Correction — | | −1 | 14 | | | | | | |
| Corrected Time of Observation | 23 | 29 | 31 | | | | | | |
| Time Difference Greenwich | −3 | 00 | 00 | | | | | | |
| Greenwich Civil Time of Observation | 20 | 29 | 31 | | | | | | |
| 1-Greenwich H.A. (Almanac) | 309 | 13.5 | | | | | | | |
| 2-Correction (hrs. & mins.) | 308 | 5.5 | | | | | | | |
| 3-Correction (seconds) | | 7.8 | | | | | | | |
| 4-G.H.A. (Time of Observation) sum of 1, 2, & 3 | 617 | 26.8 | | | | | | | |
| 5-Longitude W(−) E(+) | +44 | 08.4 | | | | | | | |
| 6-Algebraic Sum (4 & 5) subtract 360 if over 360° | 301 | 35.2' | | | | | | | |
| 7-L.H.A. (−)or(+) If over 180° use L.H.A. − 360° | −58° | 24.8' | | | | | | | |

RULES :-

1- Give K same sign as declination (d).
2- Combine K and ø (K−ø). Add arithmetically if different signs. Subtract if same signs.
3- Z is bearing from elevated pole (North pole in northern hemisphere, South pole in southern hemisphere) in direction of celestial body. (Indicated by L.H.A.)

*Figure 142. Ageton form computations to obtain LHA.*

Star observed: Procyon
Date: 25 November 1942
Latitude of position: 17° 10.2′ north
Longitude of position: 44° 08.4′ east
Watch: 1 minute, 14 seconds fast.

The observation was made and the following data were determined (for simplicity only one set of the observations is computed):

Time of first observation: $23^h\ 30^m\ 45^s$

Angle-mark to star: 20° 08′ star right of mark.

These data are entered in their respective places on the form. The time is corrected by the watch correction, which is $-1^m\ 14^s$ as the watch was fast that amount. The corrected time then is $23^h\ 30^m\ 45^s - 1^m\ 14^s = 23^h\ 29^m\ 31^s$ standard time for the 45° east time zone. The 45° east time zone is three 15° time zones from Greenwich or is 3 hours different from Greenwich time. The position of the observer is east of Greenwich which means that the sun will pass him before it will pass Greenwich. Therefore, Greenwich time is not as late as 45° standard time so 3 hours should be deducted from the standard time of observation to give the

RULES :-

1- Give K same sign as declination (d).
2- Combine K and ∅ (K~∅). Add arithmetically if different signs. Subtract if same signs.
3- Z is bearing from elevated pole (North pole in northern hemisphere, South pole in southern hemisphere) in direction of celestial body. (Indicated by L.H.A.)

| ANGLE | | ADD | SUBTRACT | ADD | SUBTRACT |
|---|---|---|---|---|---|
| L.H.A. | 58 24.8 | A 6964 | | | |
| d | +5 22.3 | B 191 | A 102865 | | |
| | | A 7155 | B 27586 | B 27586 | A 7155 |
| | | K= +10° 10.6′ | A 75279 | | |
| | | ∅= +17° 10.2 | K~∅= 6°59.6′ | B 324 | |
| | | | h= | A 27910 | B 7030 |
| L.H.A. | | A | | Z₁= 94° 20.7′ | A 125 |
| d | | B | A | | |
| | | A | B | B | A |
| | | K= | A | | |
| | | ∅= | K~∅= | B | |
| | | | h= | A | B |
| L.H.A. | | A | | Z₂= | A |
| d | | B | A | | |
| | | A | B | B | A |
| | | K= | A | | |
| | | ∅= | K~∅= | B | |
| | | | h= | A | B |
| | | | | Z₃= | A |

GRID AZIMUTH: Bearing is WEST if L.H.A. is (+), EAST if L.H.A. is (-).

| | ° | ′ | ″ | ° | ′ | ″ | ° | ′ | ″ |
|---|---|---|---|---|---|---|---|---|---|
| Bearing (Z) East or West | 94 | 20 | 42 | | | | | | |
| True Azimuth to S | 94 | 20 | 42 | | | | | | |
| Average Angle to Mark | 20 | 08 | | | | | | | |
| True Azimuth to Mark | 74 | 12 | 42 | | | | | | |
| Mean True Azimuth to Mark | | | | | | | | | |
| Grid Divergence | | | | | | | | | |
| Grid Azimuth to Mark | | | | | | | | | |

*Figure 143. Ageton table computations.*

Greenwich Civil Time. Therefore, Greenwich Civil Time of the observation was $23^h\ 29^m\ 31^s - 3^h\ 00^m\ 00^s = 20^h\ 29^m\ 31^s$. These data are entered on the standard form a part of which is shown completed in figure 138. The Greenwich hour angle of the star Procyon for $0^h$ Greenwich Civil Time, 25 November 1942, is determined from the Nautical Almanac star tables to be 309° 13.5′. Figure 139 shows the star at the time of observation, the position of the same star at $0^h$ *GCT*, and the angle *GHA* shown in the almanac. The correction (or travel of the star) for the *GCT* of the observation $20^h\ 29^m\ 31^s$ is determined by the correction tables in the Nautical Almanac following the star tables to be 308° 5.5′ + 7.8′ or 308° 13.3′. This travel or correction is shown in figure 140. The Greenwich hour angle for the star Procyon at the

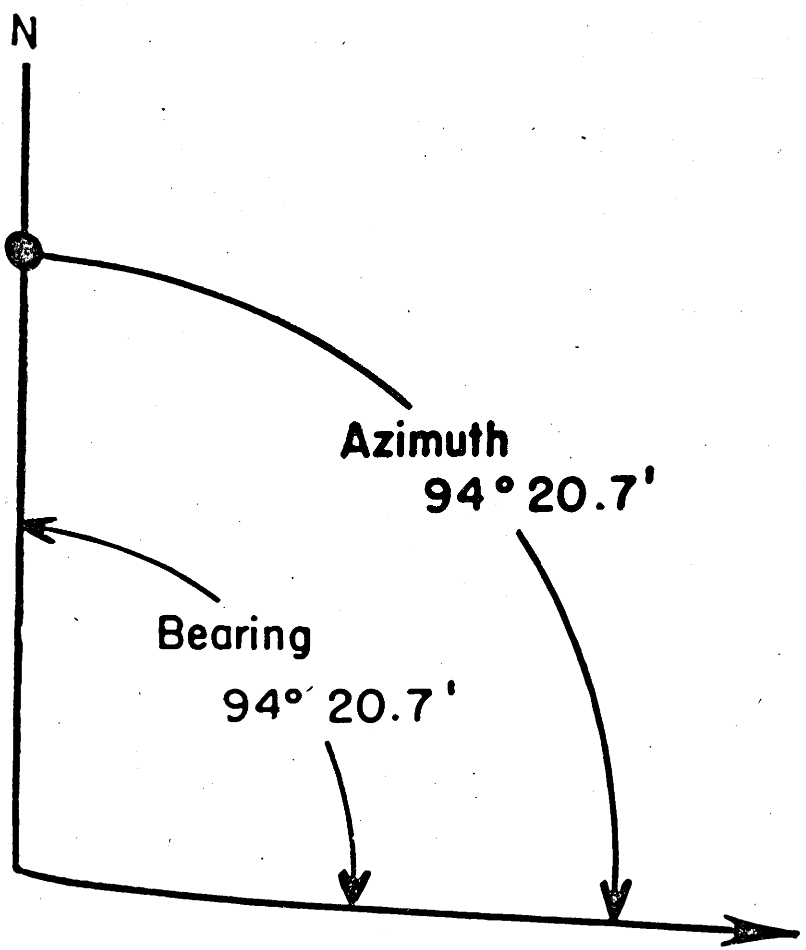



*Figure 144. Azimuth of line.*

time of observation is equal to the sum of the *GHA* at $0^h$ *GCT* plus the travel since $0^h$ *GCT* or

$$309° \ 13.5' + 308° \ 13.3' = 617° \ 26.8'$$

The local hour angle for an observer east of Greenwich will be greater than the *GHA* because the star will have revolved farther at the eastern position than it would have appeared to an observer at Greenwich. The amount of difference is the difference in longitude between the two positions, in this case 44° 08.4′, therefore, the longitude is added to the *GHA* to give the local hour angle or 617° 26.8′ + 44° 08.4′ = 661° 35.2′. The angle 661° 35.2′ is more than one complete revolution. For convenience 360° is subtracted from it to give the *LHA* of 301° 35.2′. This angle defines the position of the star from the observer's meridian which is a position 58° 24.8′ east of the observer's meridian because it lacks that number of degrees of arc of being at the observer's meridian. For simplicity in computation the *LHA* is converted to an angle less than 180°. An *LHA* of 301° 35.2′ is the same *LHA* as —58° 24.8′, obtained by subtracting 360°. This *LHA* is the one used in computations. The computations are shown in figure 142. The *LHA*, and the declination of the star (+ 5° 22.3′) as determined from the almanac, are entered in the form in the space provided. The Ageton tables are used for the remainder of the computations. The completed Ageton computations are shown in figure 143. The *A* value corresponding to an *LHA* angle

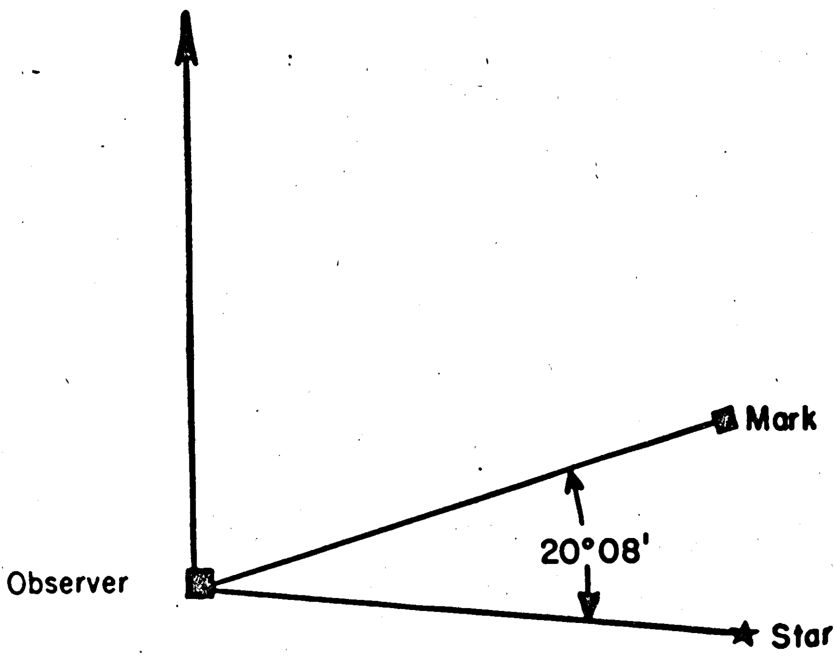



*Figure 145. Diagram of star and mark.*

of 58° 24.8′ is found in the *A* column under 58° in the Ageton tables, table LI, TM 5–236, to be 6964. This value is entered in the second column opposite the *LHA* space. The *B* value for an angle (*d*) of 5° 22.3′ which is 191 is entered in the second column opposite the "*d*" space and the *A* value (102865) for the same angle is entered in the third column. Interpolation was necessary to get these values. The next *A* value in the second column is found by adding the *A* and *B* values above it to give an *A* value of 7155. This value may also be entered in the fifth column. The *B* value corresponding to an *A* value of 7155 is found by finding the angle in the Ageton tables having an *A* value of 7155 and finding the *B* value (27586) for this angle. This number is entered in the third and fourth columns. Going to the third column, subtract the *B* value from the *A* value to give a new *A* value (75279) in the third line. The angle having an *A* value of 75279 is found in the Ageton tables to be 10° 10.6′ which is used as the value of *K* in the second column. *K* is given the same sign as the declination (*d*) of the star in this case, plus. Going to the second column the latitude (Φ) is entered under the *K* value. ~~The value of combined *K* and Φ in the third column is found by adding arithmetically the values of *K* and Φ if *K* and Φ are of different signs or subtracting if they have the same sign.~~ see C1 The *K* and Φ value is entered in the third column and the *B* value for such an angle is entered in the fourth column. *K* and Φ in this case is 6° 59.6′ and the *B* value is 324. The two *B* values in the fourth column are added to give a new *A* value of 27910. The angle having an *A* value of 27910 is determined in the tables and the *B* value (7030) corresponding to this angle is entered in the fifth column. The *B* value in the fifth column is subtracted from the *A* value to give a new *A* value of 125. The angle having an *A* value of 125 is found to be 94° 20.7′ which is the angle *Z*. This value is entered in the bearing line in the lower part of the form. The sign of the *LHA* was minus so the bearing is east of north. The Ageton system is always referred to the elevated pole, north in the Northern Hemisphere and south in the Southern Hemisphere. The bearing is therefore North 94° 20.7′ East. The azimuth of a line having such a bearing is 94° 20.7′. (See fig. 144.) The angle to the star from the mark was measured to be 20° 08′ star right of mark. (See fig. 145.) The azimuth of the mark therefore is the azimuth of the star minus the angle from the star to the mark or 94° 20.7′ —20° 08′ = 74° 12.7′ which is the true azimuth to the mark. Note that all instructions for procedure in determining signs and in making additions or subtractions are entered on the form.

## 207. Summary

This method is the most precise method presented in this manual. The results depend on the accuracy of time, and, assuming careful instrumental operation, upon the number of observations made to establish

# AZIMUTH DETERMINATION

(AGETON METHOD)

| | | | | | |
|---|---|---|---|---|---|
| STATION | B' | | | DATE | MAY 20, 1942 |
| S | SUN | LONGITUDE | 29°46'30"E | PLACE | PORT ST. JOHN |
| MARK | Buoy No. 1 | LATITUDE | 31°45'10"S | NAME | Union of So. Africa |
| | | WATCH | 3 min. 16 sec. fast | | |

| HOUR ANGLES | 1st Set | | | 2nd Set | | | 3rd Set | | |
|---|---|---|---|---|---|---|---|---|---|
| Time of Observation (0–24 hrs.) | h9 | 05 | 28 | 9 | 09 | 38 | h9 | 12 | 52 |
| Watch Correction | | 3 | 16 | | 3 | 16 | | 3 | 16 |
| Corrected Time of Observation | 9 | 02 | 12 | 9 | 06 | 20 | 9 | 09 | 36 |
| Time Difference Greenwich — | 2 | 00 | 00 | 2 | 00 | 00 | 2 | 00 | 00 |
| Greenwich Civil Time of Observation | 7 | 02 | 12 | 7 | 06 | 20 | 7 | 09 | 36 |

| | 1st Set | | 2nd Set | | 3rd Set | |
|---|---|---|---|---|---|---|
| 1-Greenwich H.A. (Almanac) | 270° | 54.6' | 270° | 54.6' | 270° | 54.6' |
| 2-Correction (hrs. & mins.) | 15 | 30.0 | 16 | 30.0 | 17 | 15.0 |
| 3-Correction (seconds) | | 3.0 | | 5.0 | | 9.0 |
| 4-G.H.A. (Time of Observation) - sum of 1, 2, & 3 | 286 | 27.6 | 287 | 29.6 | 288 | 18.6 |
| 5-Longitude W(-) E(+) | +29 | 46.5 | +29 | 46.5 | +29 | 46.5 |
| 6-Algebraic Sum (4 & 5) subtract 360 if over 360° | +316 | 14.1 | +317 | 16.1 | +318 | 05.1 |
| 7-L.H.A. (-) or (+) - if over 180° use L.H.A. - 360° | −43 | 45.9 | −42 | 43.9 | −41 | 54.9 |

RULES -

1- Give K same sign as declination (d).
2- Combine K and ø (K~ø). Add arithmetically if different signs. Subtract if same signs.
3- Z is bearing from elevated pole (North pole in northern hemisphere, South pole in southern hemisphere) in direction of celestial body. (Indicated by L.H.A.)

| ANGLE | ADD | SUBTRACT | ADD | SUBTRACT |
|---|---|---|---|---|
| L.H.A. −43 45.9 | A 16008 | | | |
| d +19 51.5 | B 2662 | A 46890 | | |
| | A 18670 | B 11950 | B 11950 | A 18670 |
| | K=+26° 34.2' | A 34940 | | |
| | ø=−31° 45.2 | K~ø=58° 19.4' | B 27973 | |
| | | h= | A 39923 | B 3761 |
| | | | Z1=134°48'42" | A 14909 |
| L.H.A. − 42 43.9 | A 16840 | | | |
| d + 19 51.6 | B 2663 | A 46887 | | |
| | A 19503 | B 11359 | B 11359 | A 19503 |
| | K=+26° 11.2' | A 35528 | | |
| | ø=−31° 45.2' | K~ø= 57° 56.4 | B 27506 | |
| | | h= | A 38865 | B 3967 |
| | | | Z2= 135°37'55" | A 15536 |
| L.H.A. − 41 54.9 | A 17520 | | | |
| d + 19 51.6 | B 2663 | A 46887 | | |
| | A 20183 | B 10904 | B 10904 | A 20183 |
| | K=+25° 53.6' | A 35983 | | |
| | ø=−31° 45.2 | K~ø= 57° 38.8' | B 27153 | |
| | | h= | A 38057 | B 4133 |
| | | | Z3=136°17'17" | A 16050 |

GRID AZIMUTH: Bearing is WEST if L.H.A. is (+), EAST if L.H.A. is (-).

| | 1st Set | | | 2nd Set | | | 3rd Set | | |
|---|---|---|---|---|---|---|---|---|---|
| Bearing (Z) East ~~or West~~ from South | 134° | 48' | 42" | 135° | 37' | 55" | 136° | 17' | 17" |
| True Azimuth to S from North | 45 | 11 | 18 | 44 | 22 | 05 | 43 | 42 | 43 |
| Average Angle to Mark | 41 | 31 | 30 | 42 | 19 | 30 | 42 | 59 | 30 |
| True Azimuth to Mark | 86 | 42 | 48 | 86 | 41 | 35 | 86 | 42 | 13 |
| Mean True Azimuth to Mark | | | | | | | 86 | 42 | 12 |
| Grid Divergence | | | | | | | | | |
| Grid Azimuth to Mark | | | | | | | | | |

*Figure 146. Sample computations.*

an average angle. Average results should give an accuracy within less than one minute of angle. The disadvantages of this method are that time must be known within an accuracy of 6 seconds, it requires an almanac, and the computations are more complex than that used in other methods.

# CHAPTER 13

# SOLAR OBSERVATION

## Section I. HOUR ANGLE METHOD

### 208. General

*a.* As most surveying is done by daylight, when observations on stars are impracticable, the reconnaissance officer should seize every chance to use observations on the sun, until he is confident of obtaining a reliable azimuth at nearly any time the sun is visible. By following the correct principles, good azimuths may be secured the first day, and the knack of making exact tangencies on the limbs of the sun will soon make possible results as close and reliable as those expected from the stars.

*b.* The most favorable position of the sun for observation for azimuth is on or near the prime vertical, due east or west of the observer. The sun is then moving most slowly in azimuth, and the horizontal angles are certain to be closer to the true angles. This holds good for both the altitude and hour angle methods, as in the latter, the instant of tangency can be more easily perceived and the effect of any error in time is minimized by the slowness of the movement.

*c.* The prismatic eyepiece with the dark sunglass yields more accurate tangencies than can be obtained from the image intercepted on a card, but it requires practice for the observer to become adept in observing with the eyepiece. If no colored glass prismatic eyepiece is available, the sun's image must be projected on a piece of white paper held 2 or 3 inches behind the eyepiece, instead of sighting on the sun direct. This is accomplished by turning the telescope on the sun and adjusting the eyepiece until the image of the cross hairs shows up clearly across the image of the sun's disk on the paper.

*d.* Exact focus on a hand-held card is difficult to maintain and at the moment of tangency the image of the cross hair disappears from the field. Finally, in order to focus the image sharply on the card, the eyepiece has to be thrown out of focus with the attendant danger of residual parallax when sighting at the mark through the telescope. However, it is felt that for the observer with little experience, observations made with a hand-held card offer less chance of error than observations with

the use of the prismatic eyepiece and the accuracy obtained is well within the allowable limits of error.

## 209. Observation of sun, field work

*a.* Center the instrument over the station and level carefully. Do not change the leveling during a single set of readings. Attach the dark glass over the prismatic eyepiece if used, and check the parallax adjustment. Point telescope at the sun and focus the image of the sun to sharp definition. Note the apparent direction of movement of the sun through the prismatic eyepiece, and call that direction west. In the following directions for an observation on the sun, it is assumed that a prismatic eyepiece is not available and a white card is used, on which is projected the image of the sun and cross hairs.

*b.* With telescope direct and the *A* vernier set to zero, sight on the azimuth mark using the lower motion. The leveling screws, lower motion, and the lightly clamped horizontal axis are not altered until the set of two observations has been completed.

*c.* Unclamp the upper horizontal plate and point on the sun with the vertical wire slightly ahead of the sun. Hold the white card behind the eyepiece of the telescope, moving it slightly if necessary to make the image of the sun show up clearly. Adjust the eyepiece until the image of the cross hairs shows up definitely across the image of the sun's disk on the paper. Move the telescope until the image of the center horizontal cross hair roughly bisects the projected image of the sun.

*d.* Keeping the image of the sun roughly bisected by the center horizontal wire, traverse the transit by means of the upper slow motion screw until the vertical cross hair falls a little west of the west limb of the sun's image, and call "Ready." At the instant the image touches the vertical hair, call "Take." The exact time is recorded, and the *A* vernier is read and recorded. Keeping the image roughly bisected as before, allow the sun to move across the field of the telescope until the vertical cross hair falls on the east limb of the sun's image; record the exact time of the contact. Between 2 and 3 minutes are required for the sun to move across the vertical cross hair. *During this time the transit must not be moved in azimuth.*

*e.* Unclamp the lower horizontal plate, reverse the telescope, and again sight on the mark as in *b* above. No reading need be taken at this point.

*f.* Unclamp the upper horizontal plate and again sight on the sun with the transit reversed, exactly as done in the first measurement, recording the reading as before.

*g.* This completes one set of readings. Two additional sets are taken and readings recorded. The mean of the times of pointing on the two limbs of the sun correspond to the readings on the horizontal circle for

the center of the image of the sun. The average time and angle for each set are recorded opposite the word "average."

*h.* This system of "doubling" the angle is the same as the system of measuring angles used in transit traverse work. The advantage gained by using this system of measuring the angle is that all errors in adjustment of the instrument, except that of the level bubble, are neutralized and the mean average angle obtained is an accurate angle.

*i.* There are various other methods of measuring the horizontal angle from the mark to the sun or stellar body, but this system is considered the simplest and chances for error in recording are less than in other methods used.

## 210. Example of field notes—Solar

The following is an example of the proper method of recording the field notes for a solar observation:

| | |
|---|---|
| Station: $B^1$ | Watch: 3 min 16 sec fast |
| Mark: Buoy No. 1 | Estimated *LHA* (check): 3 hours |
| Date: 20 May 1942 | Latitude: 31° 45′ 10″ South |
| Place: Port St. John, S. Africa | Longitude: 29° 46′ 30″ East |

| Point sighted | Time AM: West limb | | | Time AM: East limb | | | Time mean | | | Vernier *A* | Angle |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *H* | *M* | *S* | *H* | *M* | *S* | *H* | *M* | *S* | | |
| 1st set | | | | | | | | | | | |
| Mark (D) | | | | | | | | | | 0° 00′ | |
| Sun (D) | 8 | 59 | 28 | 9 | 02 | 28 | 9 | 00 | 58 | 40° 38′ | 40° 38′ |
| Mark (R) | | | | | | | | | | | |
| Sun (R) | 9 | 08 | 29 | 9 | 11 | 28 | 9 | 09 | 58 | 83° 03′ | 83° 03′ |
| | | | | Average | | | 9 | 05 | 28 | | 41° 31′ 30″ |
| 2d set | | | | | | | | | | | |
| Mark (D) | | | | | | | | | | 0° 00′ | |
| Sun (D) | 9 | 06 | 08 | 9 | 09 | 03 | 9 | 07 | 36 | 41° 55′ | 41° 55′ |
| Mark (R) | | | | | | | | | | | |
| Sun (R) | 9 | 10 | 09 | 9 | 13 | 01 | 9 | 11 | 35 | 84° 39′ | 84° 39′ |
| | | | | Average | | | 9 | 09 | 36 | | 42° 19′ 30″ |
| 3d set | | | | | | | | | | | |
| Mark (D) | | | | | | | | | | 0° 00′ | |
| Sun (D) | 9 | 08 | 59 | 9 | 11 | 48 | 9 | 10 | 24 | 42° 26′ | 42° 26′ |
| Mark (R) | | | | | | | | | | | |
| Sun (R) | 9 | 13 | 57 | 9 | 16 | 43 | 9 | 15 | 20 | 85° 59′ | 85° 59′ |
| | | | | Average | | | 9 | 12 | 52 | | 42° 59′ 30″ |

## 211. Example of azimuth determination by solar observation

~~Below~~ Figure 146 is an example of the complete computations of grid azimuth using the hour angle method, Ageton formulas and tables. For a detailed explanation of procedure of solving by the Ageton tables with the Ageton form see section VI, chapter 12. The Ageton formulae are advantageous to use in the solution of sun observations as long as the computor performs the operations in the prescribed manner and keeps in mind certain rules; however, an erroneous result may be obtained without the knowledge of the computor unless certain rules are kept in mind. These general rules may be used as a check of the solution to preclude an erroneous solution.

*a.* North is given a plus (+) sign when referring to latitude or declination, and south is given a minus sign (—).

*b.* When *LHA* is 90°, *K* is 90°, and when *LHA* is greater than 90°, *K* is greater than 90°. This is always true and will give no trouble in solution.

*c.* *Z* is the bearing of the celestial body from the elevated pole (North Pole in the Northern Hemisphere, South Pole in the Southern Hemisphere).

*d.* *Z* is always greater than 90°, except when *K* has the same sign as and is greater than the latitude. Note that the sun's declination may change appreciably during the observation.

*e.* To acquire the accuracy required for azimuth determination, interpolation must be made in the tables to obtain proper values.

# Section II. ALTITUDE METHOD

## 212. General

The movement of the sun and its change in declination was described in section II, chapter 10. The altitude method of solar observation is based on the polar distance of the sun (90° —declination of sun), the latitude of the position, and the altitude of the sun above the horizontal. The declination of the sun is dependent upon the date and time, but as the declination change is relatively slow as compared to time, the time is not as critical in this method as it is with the hour angle method. For this reason the time may be in error as much as 15 minutes without resulting in erroneous results. The declination is determined from the Nautical Almanac, and the latitude of the position is determined from a map or some navigational method to the closest tenth of a minute.

The altitude of the sun is measured by the transit, and is corrected for refraction, and in precise work for parallax.

## 213. Parallax

Parallax is the error in a measured altitude caused by the observer being on the surface of the earth rather than at its center. With stellar observations the parallax correction is infinitely small and so is ignored. However, the sun is much closer to the earth than the stars so that the altitude of the sun measured from a point on the earth's surface is not the same as if measured from the center of the earth. The effect of parallax is to make the sun's measured altitude *lower* than it would be if measured from the center of the earth. (See fig. 147.) The correction for parallax is given in table XXII, TM 5–236. As the maximum correction for parallax is 9 seconds of angle and as a 1-minute transit cannot measure angles closer than 10″ by repetition, the parallax correction is not used except in cases where precise methods are used.

## 214. Refraction

Refraction is caused by the bending of the light rays as they enter the earth's atmosphere. The effect of refraction is to make a celestial body appear *higher* than it actually is. (See fig. 131.) The refraction corrections are given in table XXI, TM 5–236. The effect of refraction is opposite in sign from that of parallax as shown in figure 148.

## 215. Polar distance

Polar distance is the distance of the celestial body in degrees and minutes of arc from the celestial pole. It is equal to 90° minus the decli-

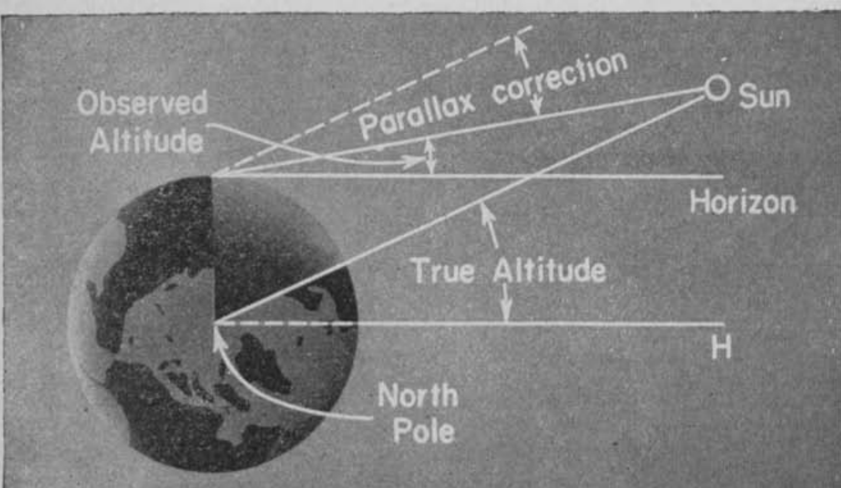



*Figure 147. Parallax correction for solar observation.*

nation of the body. The declination of the sun is given for each 2 hours of time throughout the year in the sun tables of the Nautical Almanac. An error of 5 minutes in time cannot cause more than a 1/10-minute error in azimuth because of the change in declination in the 5-minute period.

## 216. Method of observation

The observer must use more care in observation by the altitude method than is necessary with the hour angle method because the sun's image must be tangent to both cross hairs at the same time. The sun's image is so large as seen through a transit that precise setting on the center of the sun is impracticable. Therefore, two observations are made and the average is the same as if the telescope had been pointed at the center. (See fig. 149.) In order to get the two cross hairs tangent at the same time it is best to set one cross hair in an advanced position on the sun's image and keep the other cross hair tangent to the image by the slow motion screw. At the instant both cross hairs are tangent to the image, the motion of the telescope is stopped and the time, the vertical angles, and horizontal angles are recorded. Figure 150 shows the direction of movement of the sun's image and method of obtaining tangency. An observation always includes two settings with the sun's image in opposite quadrants, the average of which gives the setting that would have been made if the transit has been sighted at the sun's center. Figure 151 shows the quadrants to be used in morning and afternoon observations in the Northern Hemisphere. Note that in each case, one cross hair is set in an advanced position to allow the sun's movement to cause tangency. For an observation in the Southern Hemisphere an observer must use different quadrants. The proper quadrant to use is determined by logic and not by memory.

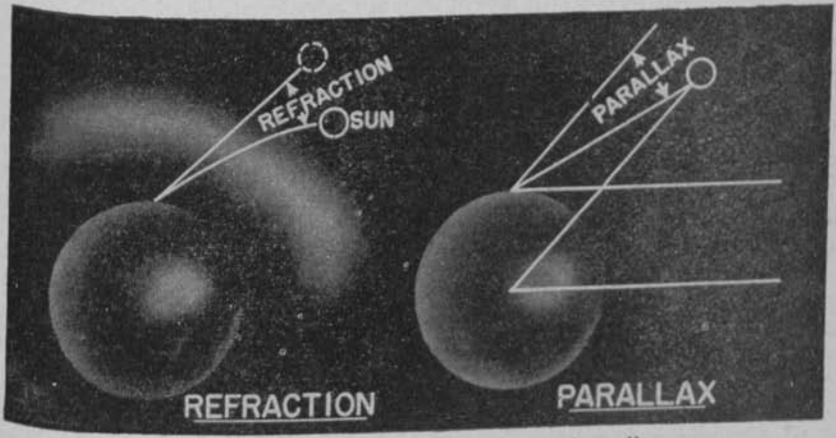



*Figure 148. Comparison of refraction and parallax.*

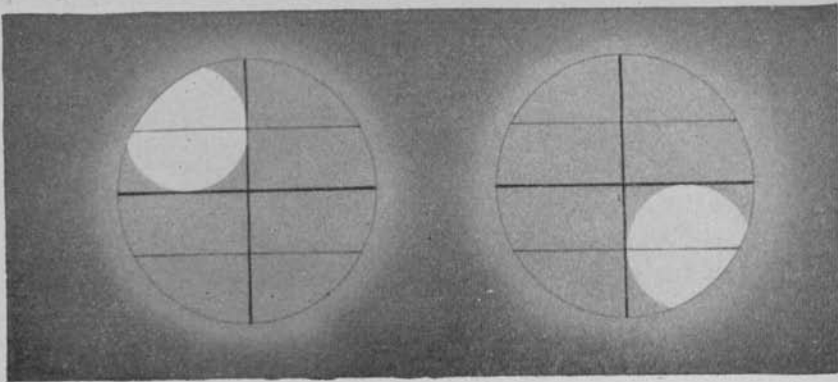


*Figure 149. Setting of cross hairs on image.*

## 217. Procedure

Set up the transit at the point from which an azimuth is to be determined. Set up an azimuth mark. Level the transit by the plate bubbles and then level the transit precisely by means of the telescope level in the same manner as described in section IV, chapter 12. The sun's image may be viewed by using a colored glass or piece of film over the objective lens of the telescope as shown in figure 153, or the image may be projected onto a card held 3" to 6" back of the eyepiece and focussing the telescope so that the cross hairs are clearly defined. (See fig. 154.) The observer turns the telescope onto the sun by observing the card and determines, by the movement of the sun's image on the card, which quadrants to use. The quadrants are selected so that the image of the sun is leaving one cross hair and approaching the other. The *A* vernier is set to zero and the telescope sighted on the azimuth mark with the lower motion. The upper motion is then released and the telescope (direct) sighted on the sun by means of the card. (Some transits are provided with a prismatic eyepiece with a colored glass. With these transits the card is unnecessary.) When the sun is sighted, clamp the upper motion. The sun's image is brought into the selected quadrant

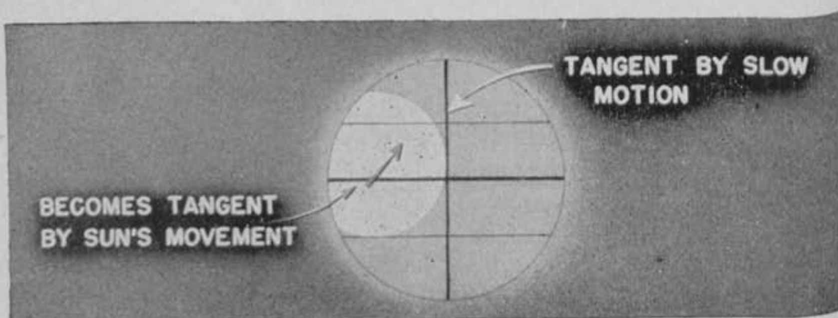



*Figure 150. Method of making cross hairs tangent to sun's image.*

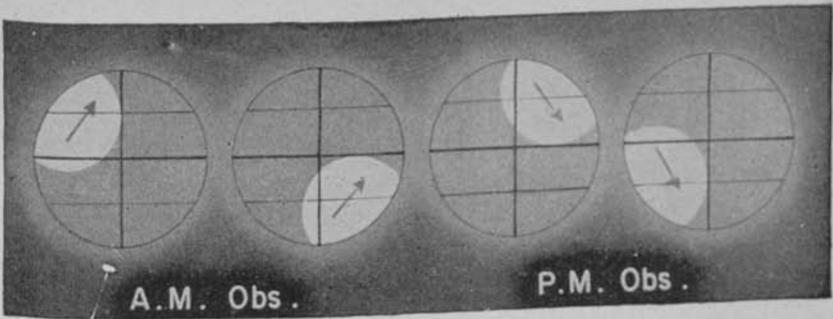



*Figure 151. Quadrants used for sighting sun.*

by operating the upper horizontal and vertical slow motion screws simultaneously. The image is set tangent to one cross hair and in position to make contact with the other cross hair by its own movement. One side of the image is kept tangent to one cross hair by the slow motion screw until the image becomes tangent to the other cross hair by its own movement. All movement of the transit is stopped at the instant of tangency and the time of the observation and readings of the vertical and horizontal verniers are recorded. Two more observations are made and recorded using the same quadrant and with the telescope direct. The time is recorded only for the first observation. The telescope is then reversed and three more observations are made using the opposite quadrant for the sun's image. The time is recorded on the last observation. In following the progress of the sun's image with the telescope reversed, the image is followed by the movement that was not used in the first set of observations as shown in figure 155. After the complete set of readings are made on the sun, the upper motion is unclamped and the azimuth mark sighted with the telescope still reversed. The horizontal scale should read 180° when sighted on the mark the second time. If it does not, it indicates that the lower motion has been moved and the observation is repeated.

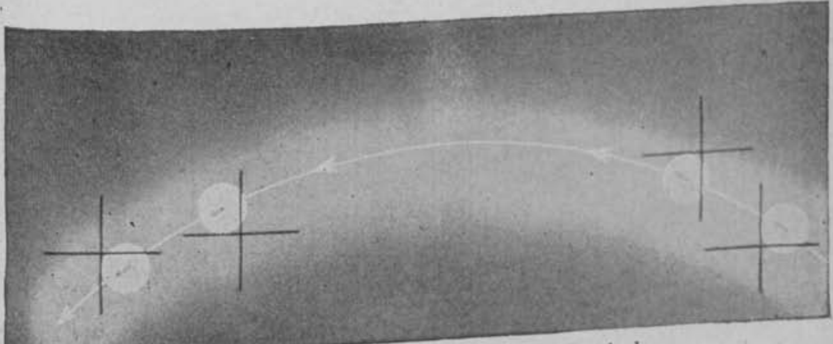


*Figure 152. Quadrants used in Southern Hemisphere.*

*Figure 153. Using film to sight on sun.*

*Figure 154. Use of card in sighting on sun.*

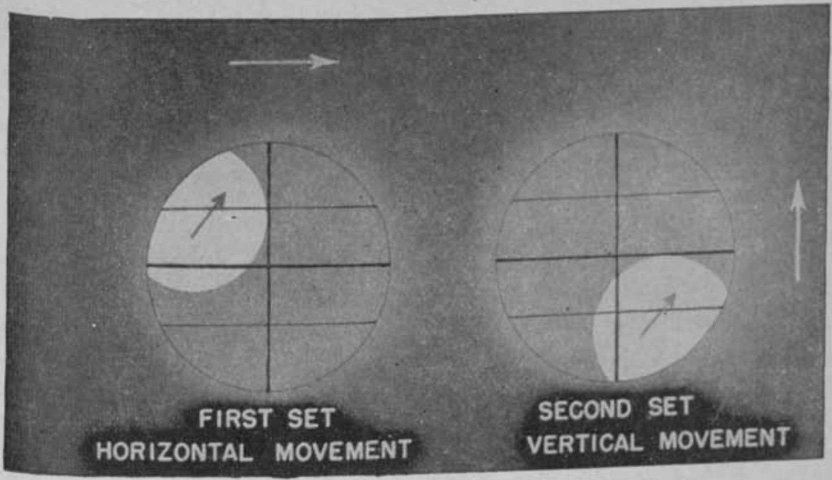



*Figure 155. Method of following sun's movement.*

**218. Notes**

Figure 156 shows a notebook made up ready for an observation. The place of observation, the latitude and longitude of this position and the date are entered in the notebook immediately. The horizontal angles and vertical angles measured are entered in the notebook along with the time of the first and last observation. The average time and

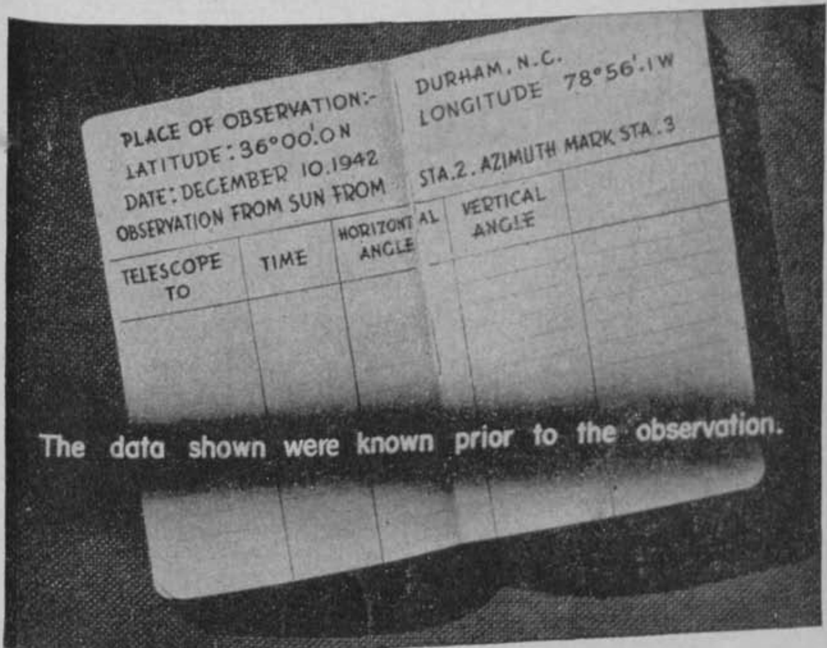



*Figure 156. Sample notebook.*

average angles are then computed remembering that the reversed readings are 180° greater than the true reading. (See fig. 157.)

## 219. Computation

The mean values are itemized for convenience. In this case they are:

Mean time of observation $= 10^h\ 34.3^m$

Mean horizontal angle $= 106°\ 14'$

Mean vertical angle $= 20°\ 46'$

The mean vertical angle must be corrected for refraction and parallax to obtain true altitude. The corrections for refraction and parallax are determined from tables XXI and XXII, TM 5–236. The corrections in this example are:

Refraction correction $= -2'\ 33''$

Parallax correction $= +08''$

(Refraction correction is always minus and parallax correction is always plus.) The corrected altitude will then be:

$$20°\ 46' - 2'\ 33'' + 08'' = 20°\ 43'\ 35'' = 20°\ 43.6'$$

The computations for the sun observations by the altitude method are based on the formula:

$$\cos \tfrac{1}{2} Z = \sqrt{\frac{\cos S \cos (S - p)}{\cos \Phi \cos h}}$$ (per cl)

$Z$ = bearing from elevated pole

$S = \tfrac{1}{2}(p + \Phi + h)$

$p$ = polar distance = 90° —declination of sun

$\Phi$ = latitude of position

$h$ = true altitude of sun

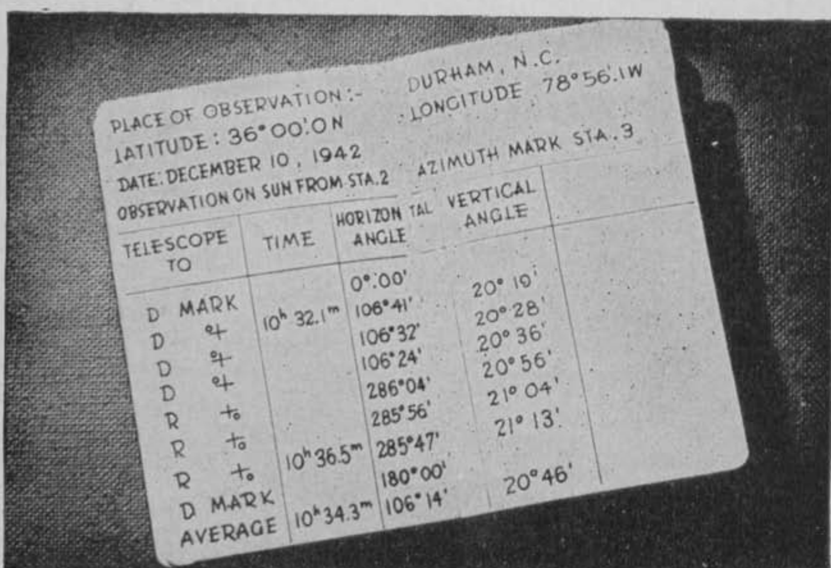



*Figure 157. Completed notebook.*

The Greenwich Civil Time of observation must be determined in order to find the declination of the sun at the time of observation. The observation was made at $10^h\ 34^m\ 20^s$ Eastern War Time or $9^h\ 34^m\ 20^s$ Eastern Standard Time. The longitude of the position was 78° 56.1′ so the time was the standard time for the 75° meridian.

$$75° \div 15° = 5$$

Greenwich time is then 5 hours different from the standard time at the position. Greenwich is east so that the sun will pass Greenwich before it does the position; so Greenwich time is later. Therefore 5 hours are added to get Greenwich Civil Time.

$$\begin{array}{rl} 9^h\ 34^m\ 20^s & \text{Eastern Standard Time} \\ +5^h\ 00^m\ 00^s & \text{Time correction} \\ \hline 14^h\ 34^m\ 20^s & = \text{Greenwich Civil Time} \end{array}$$

(See fig. 158.)

Using the Greenwich Civil Time of observation, the declination of the sun is determined to be —22° 53.6′ from the sun tables of the Nautical Almanac. Polar distance $(p) = 90° —$declination $=$

$$90° - (-22°\ 53.6') = 112°\ 53.6'$$

$$\text{Latitude } (\Phi) = 36°\ 00.0' \text{ N or } +36°\ 00.0'$$

$$\text{Altitude } (h) = 20°\ 43.6'$$

$$\cancel{S = \tfrac{1}{2}(p + \Phi + h) = \tfrac{1}{2}(112°\ 53.6' + 36°\ 00.0' + 20°\ 43.6') =}$$

$$\tfrac{1}{2}(169°\ 37.2') = 84°\ 48.6'$$

see c1

$$\cos \tfrac{1}{2} Z = \sqrt{\frac{\cos S \cos (S-p)}{\cos \Phi \cos h}}$$

$S = 84°\ 48.6'$

$S - p = 84°\ 48.6' - 112°\ 53.6'$

$= 28°\ 05.0'$

$\Phi = +36°\ 00.0'$

$h = 20°\ 43.6'$

| | | |
|---|---|---|
| Log cos $S$ | = | 8.95645 |
| Log cos $(S-p)$ | = | 9.94560 |
| Colog cos $\Phi$ | = | 0.09204 |
| Colog cos $h$ | = | 0.02906 |
| | | 19.02315 |
| Log cos ½ $Z$ | = | 9.02315 |
| ½ $Z$ | = | 83° 56.7′ |
| ~~$Z$~~ | ~~=~~ | ~~167° 53.5′~~ |

The observation was made in AM so sun was east. ~~The observation was made in Northern Hemisphere so bearing is N 167° 53.4′ E. The azimuth of sun from station 2 is 167° 53.4′. The horizontal angle measured was 106° 14′ left of the sun so the azimuth to Station 3 = 167° 53.4′ — 106° 14′ = 61° 39.4′.~~

see c1

## 220. Summary

The time of observation in this method was used only to determine the declination of the sun and as the declination changes rather slowly the time may be in error as much as 15 minutes without causing a large error in azimuth. This method requires a higher degree of precision in

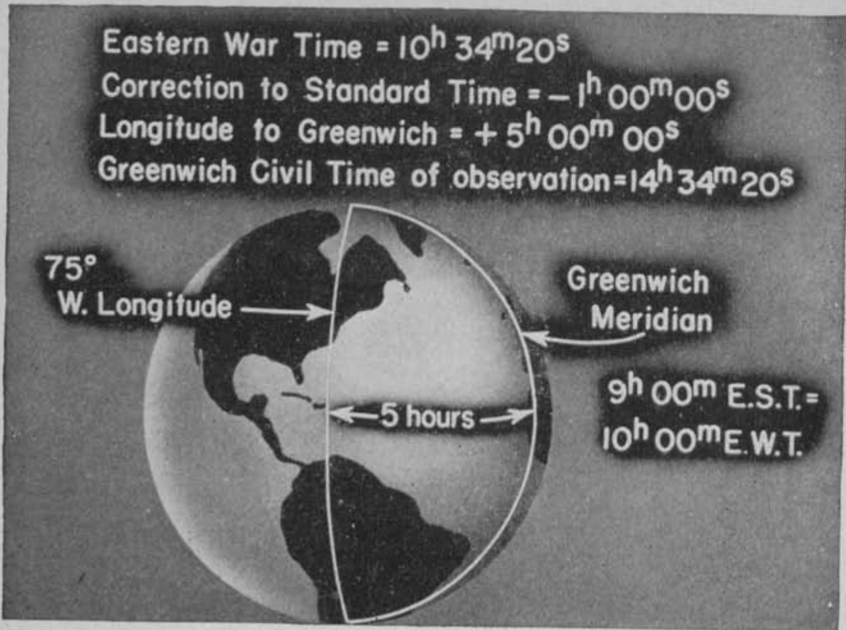



*Figure 158. Estimation of time.*

instrumental work inasmuch as tangency must be made to both cross hairs but the method is not too difficult after a little experience is gained. Reversal of the telescope corrects for most of the errors of adjustment that might be present in the instrument. The results of this method of observation should be within one minute of true azimuth if correctly performed. The formula presented in section V, chapter 12, may be used for this type of observation in the same way as the one used here.

# CHAPTER 14

# STAR IDENTIFICATION

## 221. General

It is necessary that the reconnaissance officer be able to positively identify several of the brightest stars in conducting azimuth determination. The method presented enables him to positively identify all the first magnitude (brightest) stars so that he is able to determine azimuth even though the stars visible are unfamiliar and Polaris is below the horizon. This method depends on learning to recognize three or four primary constellations and using them as a guide for locating other stars. The most readily recognized constellations are Ursa Major (The Big Dipper), Cassiopeia, Orion, Scorpio, The Square of Pegasus and Crux (The Southern Cross). Orion, Scorpio, and The Square of Pegasus are visible from either hemisphere but the others are visible mainly in their respective hemisphere. By recognizing the constellations near the celestial equator a reconnaissance officer can use them as a guide in locating new stars when he is stationed in an unfamiliar hemisphere.

## *222. Star chart units

Star identification may be simplified by the use of a star chart. Most star charts are laid off in units of sidereal time (star time) or right ascension of stars, and declination. Thus, to read the star chart, first it is necessary to determine sidereal time. Sidereal time was explained in ~~chart~~ Chapter 10. Sidereal time is not the same as standard time (your watch time corrected for 24-hour time and war time) but gains progressively throughout the year at such a rate that a complete 24-hour day is gained in each year. However, by the use of the chart in figure 159, the sidereal time may be readily determined for any hour of *standard* time for any day of any month of any year. The sidereal time determined is an approximation due to the small size of the chart, but is sufficiently accurate for determining star location.

## 223. Determination of sidereal time

Using the sidereal time chart in figure 159, mark a point on the left line (date scale) that represents the day of the month on which the side-

*Paragraphs 222 to 237, inclusive, copyright by George Mynor Hays.

real time is to be determined. Then mark a point on the right line (civil time scale) that represents the local standard time (your watch time minus 1 hour if war time is used) expressed in 24-hour time calculated from midnight to midnight. Lay a straightedge between the two marks on the left and right line and read from the middle line (sidereal time scale) at the point where the straightedge crosses the middle line. This gives the sidereal time with which to read the star chart.

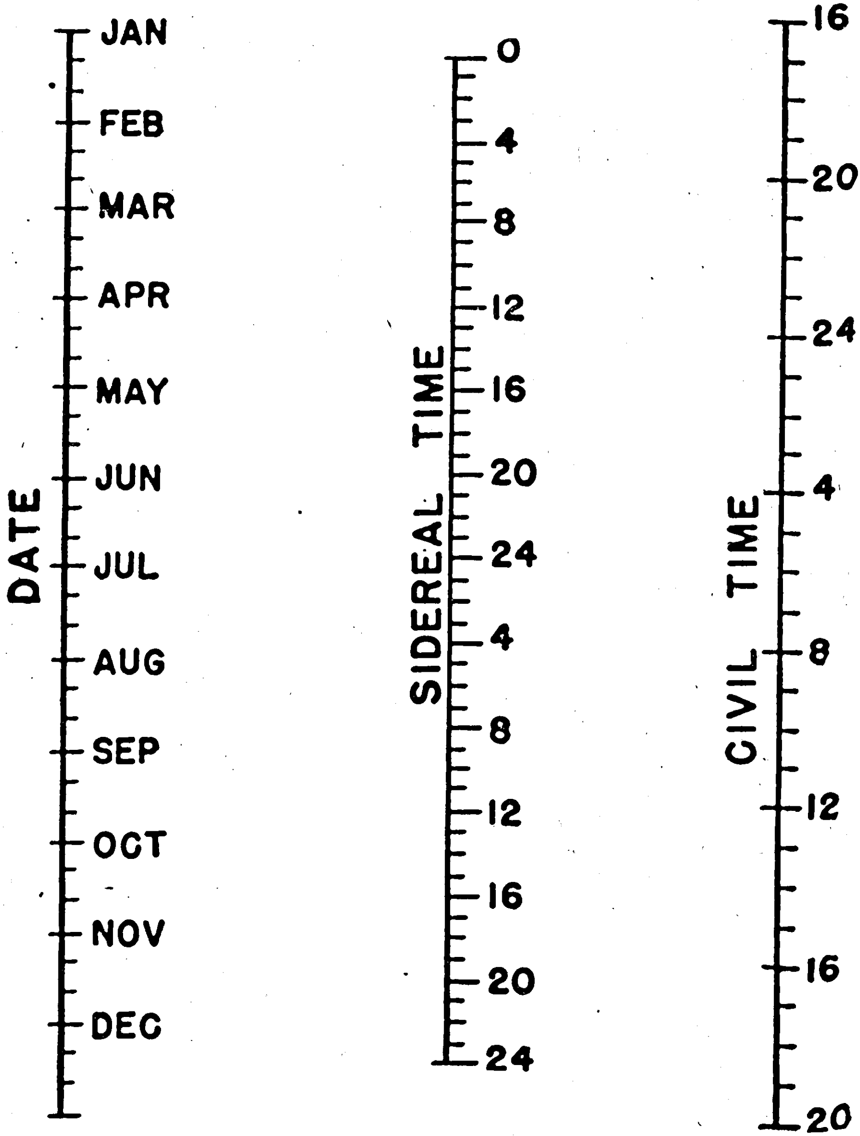



*Figure 159. Sidereal time chart.*

## 224. Star chart

The star chart (fig. 160) is similar to the star chart included in the American Nautical Almanac. Sidereal time is used to locate the north-south line passing through the zenith (the point in the sky directly over your head) on either chart. The sidereal time indicates the hour line corresponding to the observer's meridian at that time. By determining the sidereal time, the portion of the chart on the north-south line over the observer's position is indicated, thus enabling the observer to look for a collection of stars matching the constellation shown on the chart adjacent to his position.

*b.* The star chart (fig. 160) shows only prominent constellations that include the best stars for observations for azimuth determination. There are so many first magnitude (brightest) stars that an observer will rarely be tempted to use second or third magnitude (dimmer) stars for observation.

*c.* The star chart includes stars of all declinations. An observer at 40 degrees north latitude is able to see stars 40° beyond the north celestial pole and 50° below the celestial equator. Similar limits of observation hold true for other latitudes. The principle is illustrated in figure 161.

*d.* The observer's zenith may be located on the north-south hour line by using the latitude of the place of observation as the declination of the observer's zenith. In other words, an observer at 40° north latitude will observe a star of 40° north declination directly overhead when the star reaches his meridian. (See fig. 161.)

*e.* The star chart is plotted by a cylindrical projection similar to the Mercator projection for world maps. This projection causes great distortion around the poles but is sufficiently accurate from 65° north to 65° south of the Equator. For this reason, while most of the stars in the star chart are shown in their true relative positions, Polaris is apparently not in proper relation to the Big Dipper. If it will be remembered, however, that the entire top line is the North Celestial Pole, then if this line is shrunk to a single point, Polaris will be in line with the pointers of the Big Dipper. Figure 162 shows the proper relationship of stars in the vicinity of the North Celestial Pole. The star chart shows relative positions of the stars usually used for observations. There are no bright stars in the vicinity of the South Celestial Pole so that a special chart is unnecessary.

*f.* The dotted lines on the star chart indicate lines to be projected or prominent figures to look for in the sky. Since the sidereal time indicates the stars that may be expected on the line through the pole and the observer's zenith, the problem of star identification is no more complicated than the matching of topographic details with a road map.

*g.* As an example, assume that the sidereal time is 0 hours. The observer is in the Northern Hemisphere, and the star chart indicates

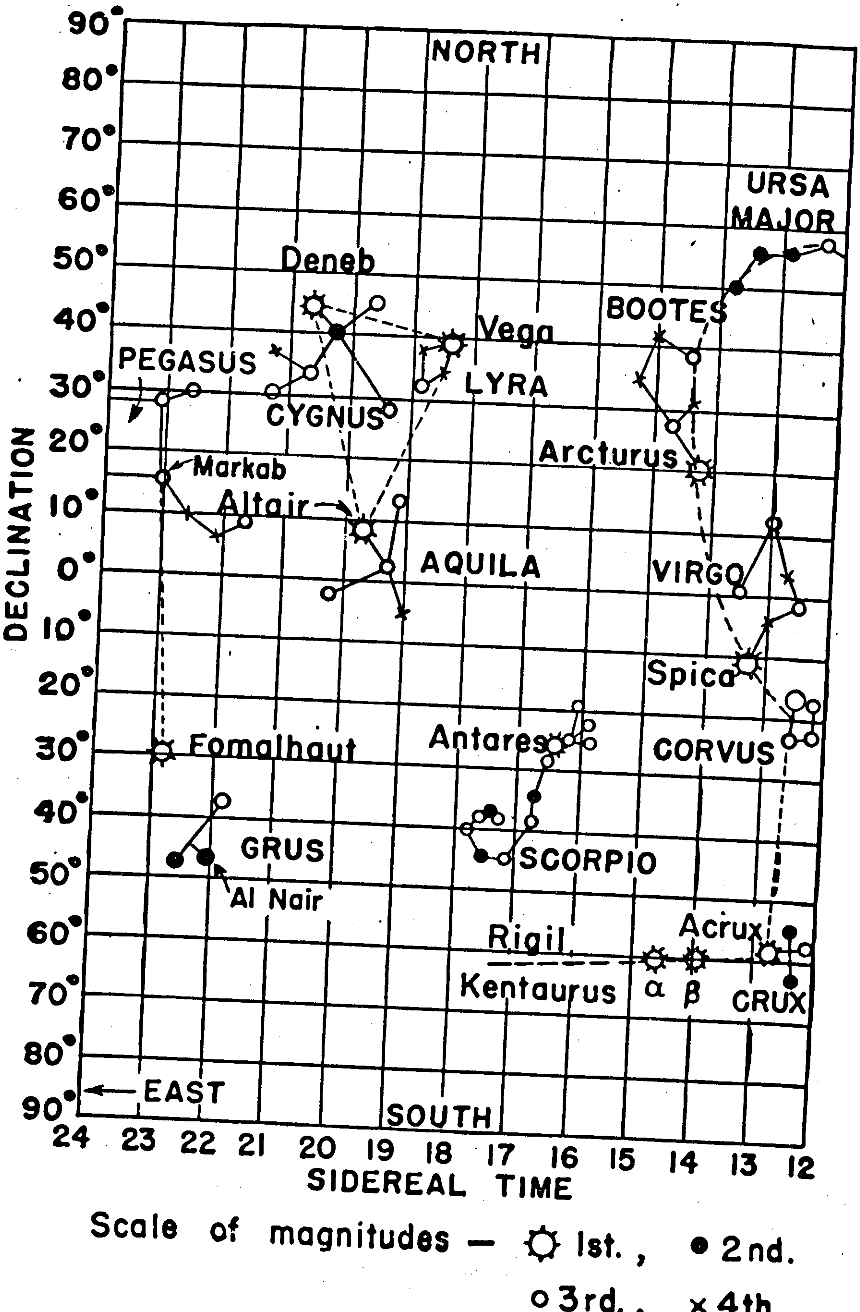



*Figure 160. Star chart (part 1).*

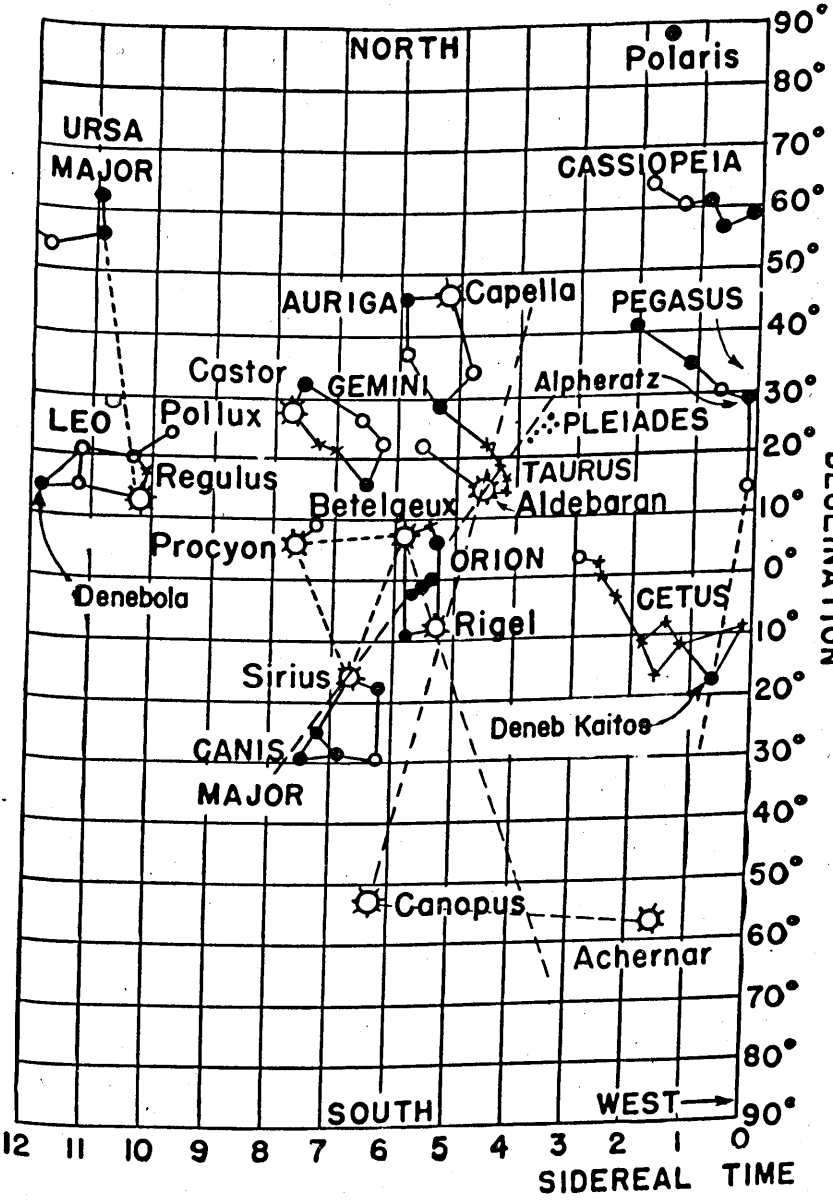



*Figure 160. Star chart (part 2).*

that the "Square of Pegasus" is nearly on the observer's meridian, or almost overhead. He looks first for the North Star (Polaris) and Cassiopeia. Now using Polaris and the west end of Cassiopeia to identify a line, extend this line beyond Cassiopeia a distance about equal to the distance from Polaris to Cassiopeia. This line will nearly coincide with one side of a large square made by four bright stars. This square is the "Square of Pegasus" which is part of the constellation Andromeda. Now using the "Square of Pegasus," extend the line of the eastern side southward and there will be one bright star, standing out amongst some dim stars, which is approximately on this line. This star is Deneb Kaitos of the constellation Cetus. Extending the western side of the square will locate Fomalhaut at a distance of three times the

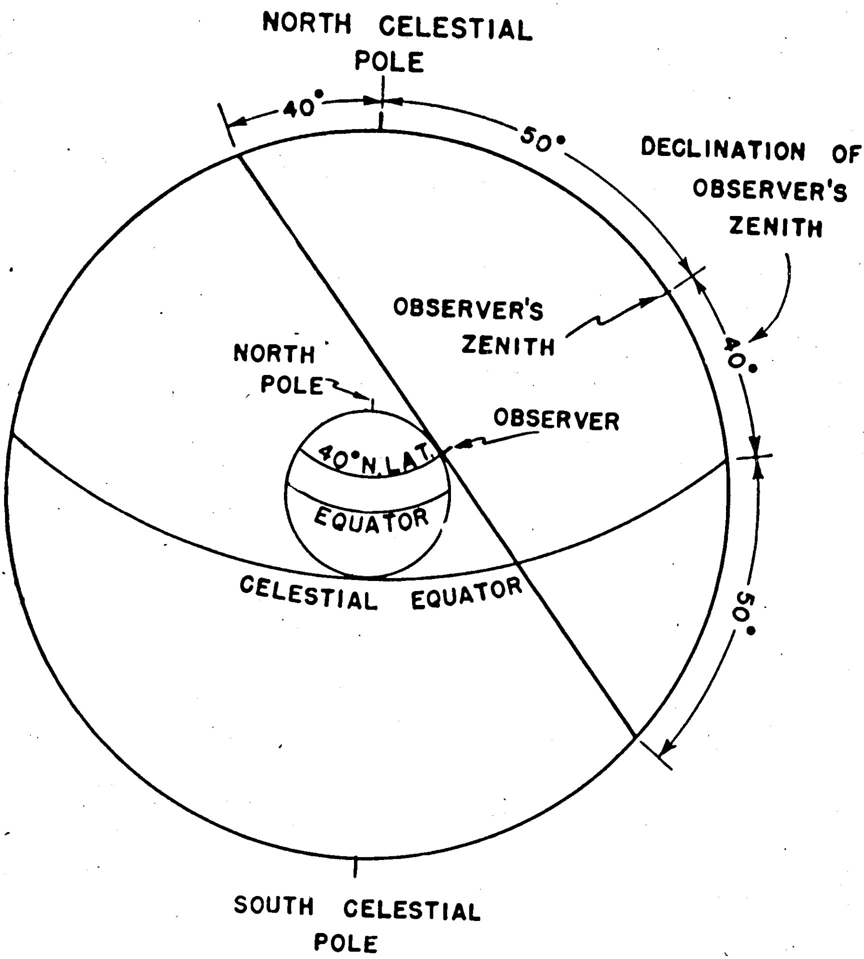



*Figure 161. Relation of latitude of position to declination of zenith.*

length of the square south of the "Square of Pegasus." Other lines shown in the star chart may be projected from constellation to constellation in a similar manner.

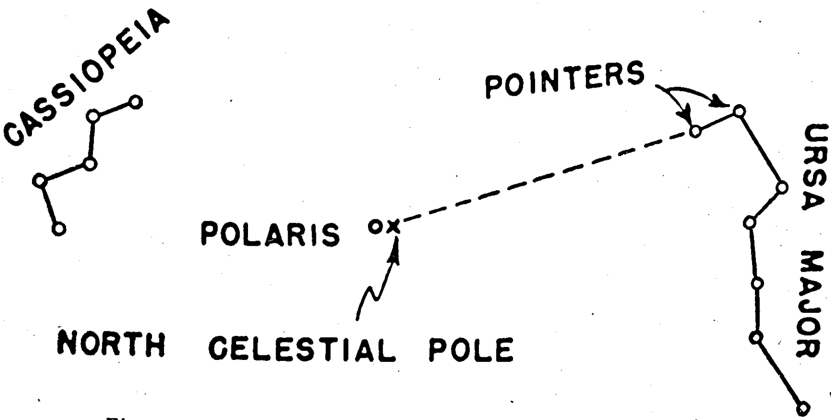



*Figure 162. Constellations in vicinity of North Celestial Pole.*

# CHAPTER 15

# USE OF BEARING CHARTS FOR ORIENTATION FOR ARTILLERY

## 225. General

The bearing charts may be used to orient guns and fire control equipment by sighting the matériel on the leading edge of the sun and correcting for the radius of the sun (16 minutes) or by sighting on a known star.

## 226. Procedure

When using the bearing charts for this purpose, a future time is selected at which time all elements of a coordinated defense will orient some one piece of fire control equipment by sighting at the leading edge of the sun or at a star previously selected. Each element of the defense is given the bearing of the celestial body at the predetermined time, prior to the time for orientation. After the basic fire control instrument selected for orientation (usually a director or BC telescope in antiaircraft artillery, aiming circle for a field artillery) has been oriented on the celestial body, the guns are oriented by keeping the fire control instrument sighted on the same celestial body and setting the guns at such an azimuth and elevation that the celestial body will apparently cross their line of sight. At the instant that the leading edge of the sun or the star reaches the point that is in line with the center of the bore of the gun, the azimuth read on the fire control instrument is transferred to the azimuth circle of the gun and the gun is then oriented. Each gun may be oriented with the fire control instrument in the same way.

## 227. Parallax

The fact that the celestial body is at an infinite distance makes any computation for parallax unnecessary as the parallax is zero.

## 228. Accuracy

The accuracy of this method of orientation is of a considerably higher degree than may be expected by a survey using ordinary field survey methods and equipment. The bearing charts may only be expected to be accurate within one degree in the case of the sun and from one to

two degrees in the case of the star chart depending on the altitude of the star. High altitudes are less precise than observations on stars at relatively low angles. However, for a coordinated defense the inaccuracy of the chart does not cause an error between elements of the unit. Inasmuch as higher headquarters has computed the bearing of the celestial body for a predetermined time, all elements will be oriented in the same direction with the same amount of basic error. The result is that all elements are coordinated precisely but the unit as a whole may have an error of 1° or 2°. If opportunity is afforded to make a precise determination of azimuth the basic error may be determined and a flat correction be applied to all elements to hold the coordination but to correct for the basic error involved by use of the charts.

## 229. Coordination

If another unit is to be coordinated with the original unit, an oriented fire control instrument of the original unit may be sighted to follow a certain celestial body. The new unit may designate a certain instrument of their unit to sight on the same celestial body. At a specified time the reading of the instrument of the original unit is transferred to the new unit to orient the instrument of the new unit. Orientation is then completed within the new unit in the same way as previously described.

## 230. Orienting lines

The use of this method will enable an organization to establish orienting lines for all elements, without the necessity of survey and consequent loss of time, or some form of registration fire and resulting betrayal of position.

## 231. Instruments

This method may be used on matériel with open sights as well as telescopic sights and in special instances some form of alidade may be used for orientation.

# CHAPTER 16

# OBSERVATIONS FOR LATITUDE

## Section I. GENERAL

### 232. Relationships

An observer standing on the north terrestrial pole would have the North Celestial Pole directly overhead or the North Celestial Pole would be his zenith. The altitude of the North Celestial Pole for this observer would be 90° and his latitude would also be 90°. If this observer moved to the Equator the North Celestial Pole would appear to be on his north horizon. The altitude of the pole would then be 0°. Figure 161 illustrates the relationships for the observer's zenith, the altitude of the North Celestial Pole and the latitude of his position. The latitude of the observer is always indicated by the altitude of the celestial pole above the observer's horizon. In figure 161, the pole is 40° above the horizon so that the latitude of his position is 40°.

### 233. Refraction

A measured altitude of a star must always be corrected for refraction as explained in paragraph 214. Refraction causes the star to appear higher than it really is. Refraction corrections are contained in table XXI, TM 5–236.

### 234. Polaris

The star Polaris has an orbit of about 1° radius about the North Celestial Pole. If the position of Polaris with respect to the North Celestial Pole is known, the altitude of Polaris may be measured and the altitude of the North Celestial Pole can be computed. Observations for latitude in the Northern Hemisphere are usually based on the star Polaris because of its convenient position, and because the computations are more simple than methods using other celestial bodies.

### 235. Culmination

The celestial sphere apparently revolves around the earth so that any point on the sphere passes the observer's meridian twice during one revolution of the sphere. The time when the point on the sphere crosses the observer's meridian is the time of culmination. Upper culmination

is the crossing of the upper half of the observer's meridian and lower culmination is the crossing of the lower half of the observer's meridian. The upper and lower culmination of stars near the pole are visible in all but very low latitudes; however stars having greater polar distances are usually visible only at upper culmination (upper transit of the meridian).

## Section II. POLARIS AT CULMINATION

### 236. General

Polaris may be observed at either upper culmination or lower culmination in most localities in the Northern Hemisphere. When Polaris is at upper culmination, the star is above the pole. Therefore, a measured altitude to Polaris at the time of upper culmination would be greater than the altitude of the North Celestial Pole by the amount of the polar distance of Polaris. Therefore, by measuring the altitude of Polaris at the time of upper culmination and correcting this measured altitude by the amount of refraction for that altitude, the altitude of the highest point of travel of Polaris around its orbit is obtained. The

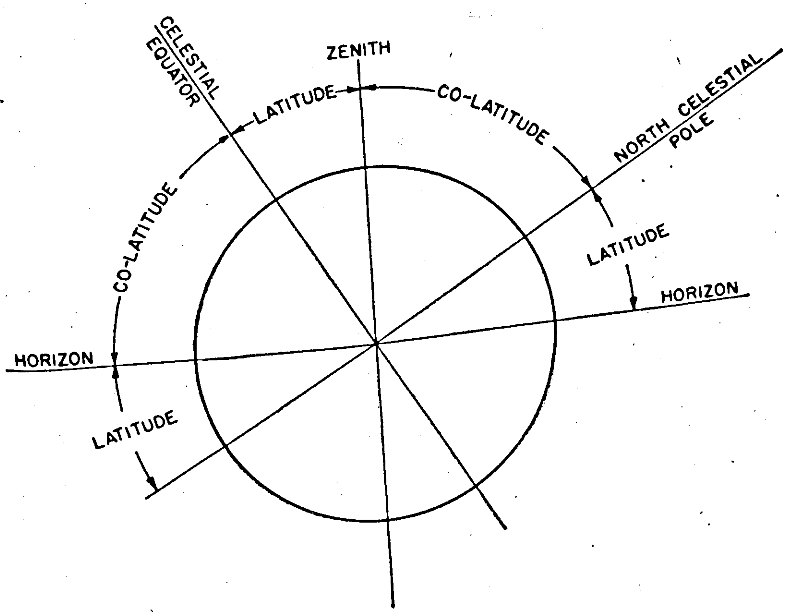



*Figure 163.*

latitude of the position from which the observation was made is determined by subtracting the polar distance of Polaris from the true altitude of Polaris at the time of upper culmination. Conversely, the polar distance will be added to the true altitude of Polaris when the star is at lower culmination.

## *237. Determination of time of culmination

*a.* The times of culminations of Polaris are listed in the American Nautical Almanac. However, if this is not available, the star may be observed at culmination by sighting a telescope on the star and observing the highest point of its travel for upper culmination, or the lowest point of its travel for lower culmination. The approximate time of culmination for any particular date may be determined from the bearing chart of the stars, chart II, sheet I (app. I). This chart may be used to determine the local civil time of culmination. Upper culmination will occur at about 01:45 sidereal time (the true sidereal time will vary from 01:44:02 to 01:46:41 in the year 1944 and the average sidereal time will be about 27 seconds later for each succeeding year). However, if the correct time is assumed to be 0145, it will only entail following the course of the star for a minute or two longer to be sure that the highest point of the orbit has been reached.

*b.* Assuming the time of upper culmination to be 0145 local sidereal time, turn to sheet I, chart II (app. I) and select the point on line *C* corresponding to the date of the year. Lay a straightedge from this point through the point of line *B* corresponding to local sidereal time of 0145. The local civil time of upper culmination will be indicated on line *A* at the point of crossing of the straightedge. The local civil time may be changed to Greenwich Civil Time by the use of table I.

*c.* The time of lower culmination may be determined in the same way as upper culmination. The time of lower culmination is approximately 1345 local sidereal time. The local sidereal time used on chart II will then be 1345 for lower culmination and 0145 for upper culmination.

## 238. Example

*a.* A reconnaissance officer decides to make an observation for latitude on 10 February 1944 using the star Polaris at culmination. No almanac is available. To determine the time of culmination he turns to chart II and lays a straightedge through the point on line *C* corresponding to 10 February and through 0145 local sidereal time on line *B*. The straightedge intersects line *A* at 1632 local civil time. This will be the time of upper culmination. However the sun is still above the horizon at 1632 so that Polaris is invisible. Therefore he uses chart II to determine the time of lower culmination. Laying the straightedge from 11 February (lower culmination will be after midnight 10 February) on

line $C$ through 1345 local sidereal time on line $B$, the straightedge intersects line $A$ at 0437 local civil time. The time of lower culmination is then 0437 local civil time. To change this time to his watch time he uses table I (app. I). The reconnaissance officer knows his longitude to be about 51° east. 51° longitude is closer to the 45° meridian than to the 60° meridian. Therefore standard time would be that of the 45° meridian. 51° —45° = 6°. 6° according to table I is equivalent to 24 minutes of time. This 24 minutes is to be added or subtracted to the local civil time to obtain standard time. 51° east is farther east than 45° east, therefore 51° east would have a later time than the 45° meridian. Therefore, standard time will be less than the 51° time or 0437 —0024 = 0413 standard time for 45° meridian. The reconnaissance officer will then set up his instrument for making the observation a few minutes prior to 0413 standard time. The time 0413 is the standard time of lower culmination of Polaris for the observer's position.

*b.* The observer sets up the transit and turns the telescope onto the star Polaris and sets the horizontal and vertical cross hair so that they bisect the star. The star should appear to travel horizontally along the horizontal cross hair and after a few minutes begin to rise in altitude. The lowest observed altitude should be the measured altitude for an

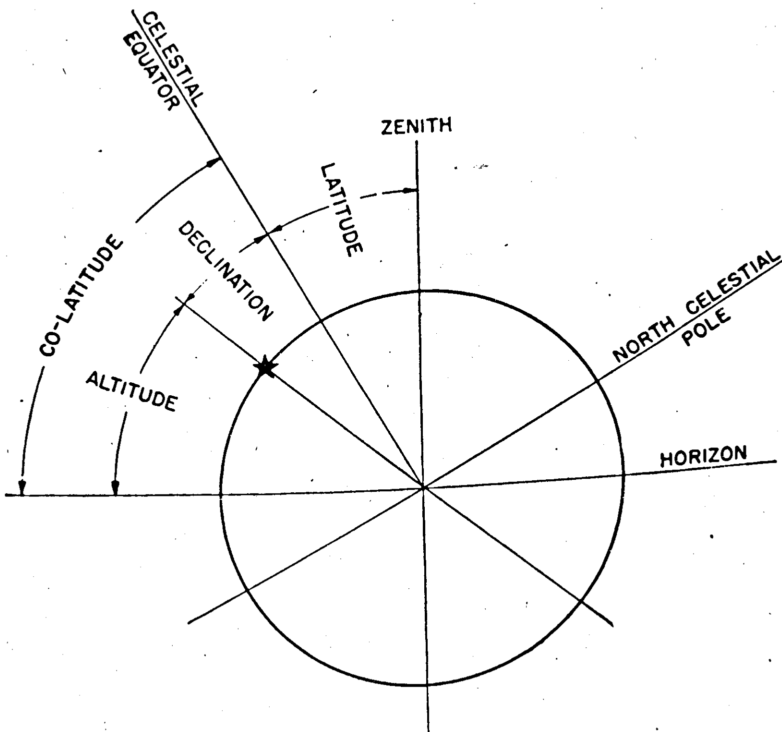



*Figure 164.*

observation at lower culmination. The observed altitude in this case was 42° 31′. This altitude must be corrected for refraction by table XXI TM 5–236.

| | | |
|---|---|---|
| Observed altitude | = | 42° 31′ |
| Correction for refraction | = | 01′ |
| Corrected altitude | = | 42° 30′ |

*c.* The polar distance of Polaris must be added to the corrected altitude of the star to give the altitude of the North Celestial Pole.

*d.* The polar distance of Polaris according to the American Nautical Almanac for 10 February 1944 is 90° —89° 00′ 09.4″ —0° 59′ 50.6″.

*e.* The polar distance by the table of mean polar distances of Polaris (par. 188) is 1° 00′ 03″.

*f.* As the transit measures angles only to the closest minute, the polar distance will be used only to the closest minute or 1° 00′ will be used.

| | | |
|---|---|---|
| Corrected altitude of Polaris | = | 42° 30′ |
| Polar distance of Polaris | = | 1° 00′ |
| Latitude of position | = | 43° 30′ North |

NOTE: The polar distance was added to the altitude of Polaris because Polaris was observed at lower culmination making the North Celestial Pole above Polaris.

## Section III. LATITUDE BY A SOUTHERN OR NORTHERN STAR

### 239. General

Latitude may be determined very easily by observing a star at its upper culmination and measuring the altitude at that time. The star will usually be a southern star in the Northern Hemisphere, and a northern star for an observer in the Southern Hemisphere, as such a star will be conveniently located for observation when at upper culmination. The declination of the star must be known and may be determined from table III (app. I). The time of culmination can be determined within a few minutes by means of the Bearing Chart of the Stars.

### 240. Selection of star

The star selected is dependent upon the time at which an observation is desired and the date of the year. An approximate time (standard time) is selected at which an observation is desired and the sidereal time corresponding to the selected standard time and date is determined by sheet I, chart II (app. I). A star is then selected that is in the opposite hemisphere (north or south) from the observer or near the celestial equator and which has a right ascension closest numerically to

the sidereal time. Having selected the star, use the hours and minutes of right ascension of that star listed in table III as the hours and minutes of sidereal time for determining the local civil time on sheet I, chart II. Right ascension in hours and minutes, for a given star is the same as the sidereal time of upper culmination of that star. Chart II may, therefore, be used to select the best star for observation and again used to determine the approximate time of upper culmination.

## 241. Theory

*a.* The latitude of a position has been shown to be the same as the altitude of the celestial pole above the horizon of this position. The observer's zenith is at an altitude of 90° above the observer's horizon and the celestial equator is at an angle of 90° from the line connecting the celestial poles. Since the angle subtended by the arc marked Co-Latitude is included in both these 90° angles, therefore the angle between the celestial equator and the observer's zenith is also equal to the latitude as shown in figure 163.

*b.* Assuming a southern star is to be observed by an observer in the northern hemisphere Co-Latitude will be equal to the altitude of the star at its highest point or upper culmination *plus* the declination of the star as shown in figure 164.

*c.* If the observer is in the Northern Hemisphere and a northern star

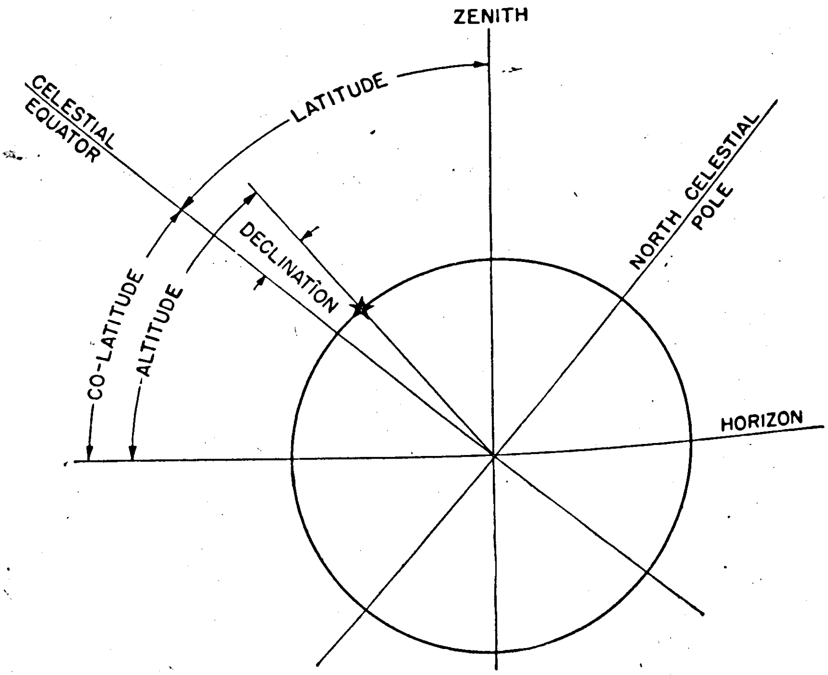



*Figure 165.*

is to be observed, the Co-Latitude will be equal to the altitude of the star *minus* the declination of the star as shown in figure 165. Having obtained the Co-Latitude of the position, subtracting this from 90° will give the latitude.

## 242. Example

*a.* A reconnaissance officer desires to determine the latitude of a position on 10 March 1944. The most convenient time is 2000 or 2100. Turning to sheet I, chart II, appendix I, he lays a straightedge from 10 March on line *"C"* to 2100 on line *A* and sees that the sidereal time shown on line *B* is about 8 hours. Turning to table III, he finds a star having a right ascension of about 8 hours and not too far from the celestial equator, that is a star having a small declination or one in the opposite hemisphere (in this case southern). He finds the star Pollux to be closest to 8 hours right ascension but the declination is rather large. However Procyon has a right ascension of $7^{hr}$ $36^{min}$ and a declination of only + 5° 22.1′ which is about right for his purpose. Now using the $7^{hr}$ $36^{min}$ he turns to sheet I, chart II, and lays a straightedge from $7^{hr}$ $36^{min}$ on line *B* to 10 March on line *C* and reads the local civil time from line *A* as 2033. 2033 will then be the local civil time of upper culmination of the star Procyon on 10 March. Now his approximate longitude is known to be about 81° west. 81° west is closest to the 75° west time zone meridian so his meridian will be 6° west of the standard time meridian. 6° longitude according to table I, is equal to 24 minutes of time. His local civil time will be 24 minutes different from the standard time. He is west of the standard time zone meridian (75°) which means the sun will pass the 75° meridian before it will pass his meridian (81°) so the 75° meridian will have a later time. Therefore the 24 minutes must be added to his local civil time to obtain the standard time. The standard time of upper culmination will then be the local civil time (2033) plus 24 minutes correction or 2057 standard time.

*b.* A few minutes before 2057 the reconnaissance officer sets up the transit and sights the star Procyon setting the horizontal cross hair exactly on the star. The star is followed until it begins to drop below the horizontal cross hair. The highest elevation reached by the star is read on the vertical scale of the transit and recorded. The observation was made in the Northern Hemisphere and as the star's declination is + 5° 22.1′, the star is a northern star as shown in figure 165. The altitude was measured to be 36° 47′. The Co-Latitude will be 36° 47′ —5° 22′ = 31° 25′. The latitude will be 90° —31° 25′ = 58° 35′ north. This method is only as accurate as the least reading of the transit so that the determination is only to the closest minute of latitude.

# *APPENDIX I

# CHARTS AND TABLES

## CHART I

### 1. Method of use of bearing chart of the sun

*a.* The bearing chart of the sun is based on a knowledge of the latitude of the place of observation within 1°, the longitude of the place within 1 or 2 minutes if possible, the Greenwich Civil Time within an accuracy of 1 or 2 minutes, and the date of the year. The average error of azimuth determination by the use of this chart should not exceed 1°.

*b.* To use the chart, the observer's watch should be checked so that Greenwich Civil Time at any instant may be known. The Greenwich Civil Time is then changed to local civil time by means of Table I. If the observer's position is east of the Greenwich meridian the longitude conversion time should be added to Greenwich Civil Time and conversely if the position is west of the Greenwich meridian, the time should be subtracted. The local civil time is then changed to local apparent time by adding algebraically the minutes of time indicated in table II for the date of observation.

*c.* An itemization of values should then be made for known factors as follows:

Latitude =
Apparent time =
Date =

*d.* Locate the proper date on line "*A*" and connect this point with the point on line "*C*" corresponding to the apparent time. Read the reference No. *M*, on line "*B*" at the intersection of the straight line connecting lines "*A*" and "*C*."

*e.* With the reference No. *M*, so obtained, turn to sheet II. Add or subtract the latitude of the place of observation to the reference No. *M*. (The rules for determining whether to add or subtract are given on line "*D*.") Locate the point on line "*D*" corresponding to the arithmetical sum of *M* and the latitude. With a straight line, connect this point to a point on line "*F*" corresponding to the value of reference No. *M*. The

intersection of this straight line with line "*E*" will give the value of reference No. *P*.

*f.* Turn to sheet III. Using a straightedge connect the point on line "*E*" corresponding to the value of reference No. *P* with the point indicating the apparent time of the observation on line "*H*."

*g.* The point of crossing of this line with line "*G*" indicates the bearing of the sun. The angles read from 1′ to 179° 59′. Values under 90° are only possible when the reference No. *M* was added to the latitude and their sum was less than 90°. The bearing is always measured from the elevated pole (south in the Southern Hemisphere and north in the Northern Hemisphere) and the bearing is east for morning observations and west for afternoon observations.

## 2. Methods of use of bearing chart in high latitudes

In high latitudes, there are periods of the year when the sun may be visible between 1800 (6 PM) and 0600 (6 AM). The times listed on the chart are only for 0604 to 1756. When a bearing is desired between 1800 and 0600, the chart may be used to determine the bearing by the following rules:

*a.* ~~Add 12 hours to apparent time and use this new time on both lines "*C*" and "*H*" (if the new time is over 2400).~~

*b.* On line "*D*" subtract reference No. *M* from latitude instead of the rules as shown on chart.

*c.* The bearing will always be under 90° when the time is between 1800 and 0600.

## 3. Sample problem using chart I

Required: Bearing of the sun at Camp Davis, North Carolina.

| | | |
|---|---|---|
| Given: | Time, | 1000 Eastern War Time. |
| | Date, | 17 May 1943. |
| | Latitude, | 34° North (closest degree). |
| | Longitude, | 77° 33′ West (closest minute). |

Solution:

| | |
|---|---|
| 1000 | Eastern War Time |
| —100 | for war time |
| 0900 | Eastern Standard Time |
| +500 | (EST is 75° or fifth time zone time) |
| 1400 | Greenwich Civil Time |
| | Correction for longitude 77° 33′ West by table I $= 5^{hr}\ 08^{min} + 2^{min}\ 12^{sec} = 5^{hr}\ 10^{min}\ 12^{sec}$ (disregard seconds). |
| —510 | (Sun passed Greenwich before it passed us so Greenwich time is later than ours.) |
| 0850 | Local civil time |
| + 4 | (By table II for 17 May) |
| 0854 | Local apparent time |

*Table I. Conversion of longitude into time*

| Degrees of longitude into hours and minutes of time | | | | | | | | | | | | Minutes of longitude to minutes of time | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deg. | H. M. | Deg. | H. M. | Deg. | H. M. | Deg. | H. M. | Deg. | H. M. | Deg. | H. M. | Min.— | M. S. | Min.— | M. S. |
| 0 | 0 00 | 30 | 2 00 | 60 | 4 00 | 90 | 6 00 | 120 | 8 00 | 150 | 10 00 | 0 | 0 00 | 30 | 2 00 |
| 1 | 0 04 | 31 | 2 04 | 61 | 4 04 | 91 | 6 04 | 121 | 8 04 | 151 | 10 04 | 1 | 0 04 | 31 | 2 04 |
| 2 | 0 08 | 32 | 2 08 | 62 | 4 08 | 92 | 6 08 | 122 | 8 08 | 152 | 10 08 | 2 | 0 08 | 32 | 2 08 |
| 3 | 0 12 | 33 | 2 12 | 63 | 4 12 | 93 | 6 12 | 123 | 8 12 | 153 | 10 12 | 3 | 0 12 | 33 | 2 12 |
| 4 | 0 16 | 34 | 2 16 | 64 | 4 16 | 94 | 6 16 | 124 | 8 16 | 154 | 10 16 | 4 | 0 16 | 34 | 2 16 |
| 5 | 0 20 | 35 | 2 20 | 65 | 4 20 | 95 | 6 20 | 125 | 8 20 | 155 | 10 20 | 5 | 0 20 | 35 | 2 20 |
| 6 | 0 24 | 36 | 2 24 | 66 | 4 24 | 96 | 6 24 | 126 | 8 24 | 156 | 10 24 | 6 | 0 24 | 36 | 2 24 |
| 7 | 0 28 | 37 | 2 28 | 67 | 4 28 | 97 | 6 28 | 127 | 8 28 | 157 | 10 28 | 7 | 0 28 | 37 | 2 28 |
| 8 | 0 32 | 38 | 2 32 | 68 | 4 32 | 98 | 6 32 | 128 | 8 32 | 158 | 10 32 | 8 | 0 32 | 38 | 2 32 |
| 9 | 0 36 | 39 | 2 36 | 69 | 4 36 | 99 | 6 36 | 129 | 8 36 | 159 | 10 36 | 9 | 0 36 | 39 | 2 36 |
| 10 | 0 40 | 40 | 2 40 | 70 | 4 40 | 100 | 6 40 | 130 | 8 40 | 160 | 10 40 | 10 | 0 40 | 40 | 2 40 |
| 11 | 0 44 | 41 | 2 44 | 71 | 4 44 | 101 | 6 44 | 131 | 8 44 | 161 | 10 44 | 11 | 0 44 | 41 | 2 44 |
| 12 | 0 48 | 42 | 2 48 | 72 | 4 48 | 102 | 6 48 | 132 | 8 48 | 162 | 10 48 | 12 | 0 48 | 42 | 2 48 |
| 13 | 0 52 | 43 | 2 52 | 73 | 4 52 | 103 | 6 52 | 133 | 8 52 | 163 | 10 52 | 13 | 0 52 | 43 | 2 52 |
| 14 | 0 56 | 44 | 2 56 | 74 | 4 56 | 104 | 6 56 | 134 | 8 56 | 164 | 10 56 | 14 | 0 56 | 44 | 2 56 |
| 15 | 1 00 | 45 | 3 00 | 75 | 5 00 | 105 | 7 00 | 135 | 9 00 | 165 | 11 00 | 15 | 1 00 | 45 | 3 00 |
| 16 | 1 04 | 46 | 3 04 | 76 | 5 04 | 106 | 7 04 | 136 | 9 04 | 166 | 11 04 | 16 | 1 04 | 46 | 3 04 |
| 17 | 1 08 | 47 | 3 08 | 77 | 5 08 | 107 | 7 08 | 137 | 9 08 | 167 | 11 08 | 17 | 1 08 | 47 | 3 08 |
| 18 | 1 12 | 48 | 3 12 | 78 | 5 12 | 108 | 7 12 | 138 | 9 12 | 168 | 11 12 | 18 | 1 12 | 48 | 3 12 |
| 19 | 1 16 | 49 | 3 16 | 79 | 5 16 | 109 | 7 16 | 139 | 9 16 | 169 | 11 16 | 19 | 1 16 | 49 | 3 16 |
| 20 | 1 20 | 50 | 3 20 | 80 | 5 20 | 110 | 7 20 | 140 | 9 20 | 170 | 11 20 | 20 | 1 20 | 50 | 3 20 |
| 21 | 1 24 | 51 | 3 24 | 81 | 5 24 | 111 | 7 24 | 141 | 9 24 | 171 | 11 24 | 21 | 1 24 | 51 | 3 24 |
| 22 | 1 28 | 52 | 3 28 | 82 | 5 28 | 112 | 7 28 | 142 | 9 28 | 172 | 11 28 | 22 | 1 28 | 52 | 3 28 |
| 23 | 1 32 | 53 | 3 32 | 83 | 5 32 | 113 | 7 32 | 143 | 9 32 | 173 | 11 32 | 23 | 1 32 | 53 | 3 32 |
| 24 | 1 36 | 54 | 3 36 | 84 | 5 36 | 114 | 7 36 | 144 | 9 36 | 174 | 11 36 | 24 | 1 36 | 54 | 3 36 |
| 25 | 1 40 | 55 | 3 40 | 85 | 5 40 | 115 | 7 40 | 145 | 9 40 | 175 | 11 40 | 25 | 1 40 | 55 | 3 40 |
| 26 | 1 44 | 56 | 3 44 | 86 | 5 44 | 116 | 7 44 | 146 | 9 44 | 176 | 11 44 | 26 | 1 44 | 56 | 3 44 |
| 27 | 1 48 | 57 | 3 48 | 87 | 5 48 | 117 | 7 48 | 147 | 9 48 | 177 | 11 48 | 27 | 1 48 | 57 | 3 48 |
| 28 | 1 52 | 58 | 3 52 | 88 | 5 52 | 118 | 7 52 | 148 | 9 52 | 178 | 11 52 | 28 | 1 52 | 58 | 3 52 |
| 29 | 1 56 | 59 | 3 56 | 89 | 5 56 | 119 | 7 56 | 149 | 9 56 | 179 | 11 56 | 29 | 1 56 | 59 | 3 56 |

Set straightedge (a thread makes a good straightedge for use on the chart) at interpolated position of 17 May on line "*A*," and 8:54 on line "*C*." Reference No. *M* is read on line "*B*" to be 63°.

| | |
|---|---|
| 63° | Reference No. *M* |
| +34° | Latitude |
| 97° | (Add because of rule shown on line "*D*") |

Connect 97° on line "*D*" with 63° (reference No. *M*) on line "*F*," and read reference No. *P* on line "*E*" to be 78.8.

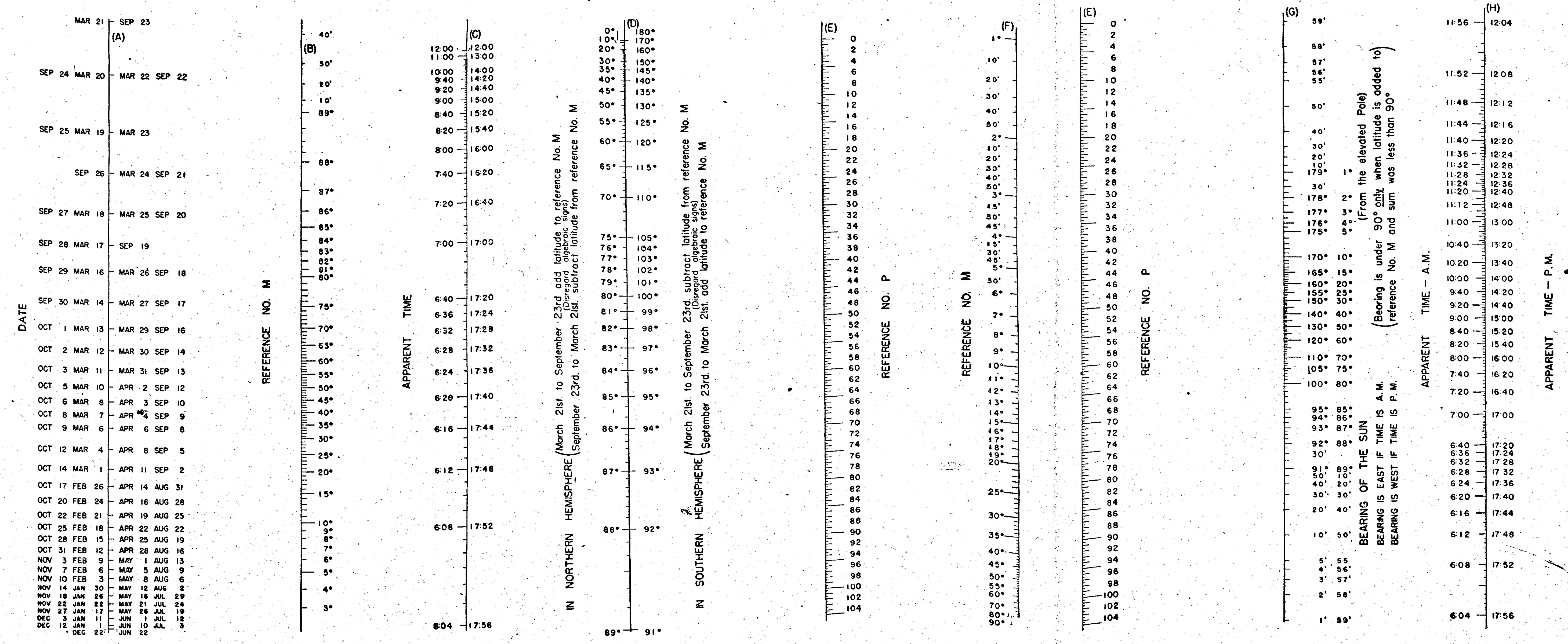
Connect 78.8 on line "*E*" with 8:54 (apparent time) on line "*H*," and read the bearing of the sun from line "*G*." The bearing indicated is 97° 30′ or 82° 30′. By the rules given on line "*G*" the bearing is known to be north 97° 30′ east. (True bearing by Hydrographic Office Publication No. 71 is M 97° 19′ E.)

*Table II. Correction in minutes to convert to apparent time.*

| | DATE | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MONTH | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Jan | -3 | -4 | -4 | -5 | -5 | -5 | -6 | -6 | -7 | -7 | -8 | -8 | -8 | -9 | -9 | -9 |
| Feb | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -14 |
| Mar | -13 | -12 | -12 | -12 | -12 | -12 | -11 | -11 | -11 | -11 | -10 | -10 | -10 | -10 | -9 | -9 |
| Apr | -4 | -4 | -4 | -3 | -3 | -3 | -3 | -2 | -2 | -2 | -1 | -1 | -1 | -1 | 0 | 0 |
| May | +3 | +3 | +3 | +3 | +3 | +3 | +3 | +4 | +4 | +4 | +4 | +4 | +4 | +4 | +4 | +4 |
| June | +3 | +2 | +2 | +2 | +2 | +2 | +2 | +1 | +1 | +1 | +1 | +1 | 0 | 0 | 0 | 0 |
| July | -3 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 |
| Aug | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -5 | -5 | -5 | -5 | -5 | -5 | -4 |
| Sep | 0 | 0 | 0 | +1 | +1 | +1 | +2 | +2 | +2 | +3 | +3 | +3 | +4 | +4 | +4 | +5 |
| Oct | +10 | +10 | +11 | +11 | +11 | +11 | +12 | +12 | +12 | +13 | +13 | +13 | +13 | +14 | +14 | +14 |
| Nov | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +15 |
| Dec | +11 | +11 | +11 | +10 | +10 | +9 | +9 | +9 | +8 | +8 | +7 | +7 | +6 | +6 | +5 | +5 |

| | DATE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MONTH | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| Jan | -10 | -10 | -10 | -11 | -11 | -11 | -12 | -12 | -12 | -12 | -13 | -13 | -13 | -13 | -13 |
| Feb | -14 | -14 | -14 | -14 | -14 | -14 | -14 | -13 | -13 | -13 | -13 | -13 | -13 | | |
| Mar | -9 | -9 | -8 | -8 | -8 | -7 | -7 | -7 | -6 | -6 | -6 | -5 | -5 | -5 | -5 |
| Apr | 0 | 0 | +1 | +1 | +1 | +1 | +1 | +2 | +2 | +2 | +2 | +2 | +3 | +3 | |
| May | +4 | +4 | +4 | +4 | +4 | +4 | +4 | +3 | +3 | +3 | +3 | +3 | +3 | +3 | +3 |
| June | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | |
| July | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| Aug | -4 | -4 | -4 | -4 | -3 | -3 | -3 | -3 | -2 | -2 | -2 | -2 | -1 | -1 | -1 |
| Sep | +5 | +5 | +6 | +6 | +6 | +7 | +7 | +8 | +8 | +8 | +9 | +9 | +9 | +10 | |
| Oct | +14 | +15 | +15 | +15 | +15 | +15 | +15 | +16 | +16 | +16 | +16 | +16 | +16 | +16 | +16 |
| Nov | +15 | +15 | +15 | +15 | +14 | +14 | +14 | +14 | +13 | +13 | +13 | +12 | +12 | +12 | |
| Dec | +4 | +4 | +3 | +3 | +2 | +2 | +1 | +1 | 0 | 0 | -1 | -1 | -2 | -2 | -3 |

*Chart I. Bearing chart of the sun*



## 4. Methods of use of the bearing chart of the stars

*a.* The bearing chart of the stars is based on knowledge of the latitude of the place of observation within 1°, the longitude of the place within 1 or 2 minutes if possible, the Greenwich Civil Time within an accuracy of 1 or 2 minutes, and the date of the year. The average error of azimuth determination by the use of this chart should not exceed 1½°. ~~Bearings taken on stars relatively close to the horizon are more precise than bearings on stars that are near their hightest altitude.~~ dele c/

*b.* To use the chart, the observer's watch should be checked so that Greenwich Civil Time at any instant may be known. The Greenwich Civil Time is changed to local civil time by means of table I. If the observer's position is east of the Greenwich meridian the longitude conversion time should be added to Greenwich Civil Time and conversely, if the position is west of the Greenwich meridian, the time should be subtracted.

*c.* An itemization of values should be made for known factors as follows:

Latitude =
Local civil time =
Date =
Local sidereal time =
Star name =
Local hour angle =
Reference No. M =
Combined M and L =
Reference No. P =
Bearing =

*d.* Starting with the given data, latitude, date, and local civil time, turn to sheet I, connect point on line *"A"* corresponding to the local civil time, by a straightedge, with the point on line *"C"* corresponding to the date. Read the local sidereal time from line *"B"* at the intersection of line *"B"* and the straightedge.

*e.* Turn to sheet II and using the local sidereal time found on sheet I, and the name of the star, connect the points on line *"D"* and line *"F"* with a straightedge and read the local hour angle at the intersection of line and the straightedge.

*f.* Turn to sheet III and using the local hour angle just found, connect the point on line *"G"* corresponding to the star name by means of a straightedge with the point on line *"J"* corresponding to the local hour angle and read reference No. M at the intersection of the straightedge and line *"H."*

*g.* Turn to sheet IV and add or subtract the latitude of the position to reference No. *M* as shown by the rules on line "*K*."

*h.* Connect the point on line "*K*" corresponding to the combined reference No. *M* and latitude by a straightedge with the point on line "*M*" corresponding to reference No. *M*. Read reference No. *P* at the intersection of line "*L*" and the straightedge.

*i.* Turn to sheet V and connect the point on line "*L*" corresponding to reference No. *P* by a straightedge with the point on line "*O*" corresponding to the local hour angle found on sheet II. Read the bearing of the star at the intersection of line "*N*" and the straightedge. The bearing will be from the elevated pole (North Pole in the Northern Hemisphere, South Pole in the Southern Hemisphere) and will be east or west of north as indicated on line "*E*," sheet II. The bearing will be under 90° *only* when latitude is added to reference No. *M* and sum is less than 90°.

## 5. Sample problem using chart II

*a.* A battalion reconnaissance officer decides to orient the matériel of a gun battalion on the star Fomalhaut. The date is 20 September 1943 and the time at which he expects to be ready for orientation is 0400. His position is known to be at latitude 15° south, longitude 60° 28′ west.

*b.* To determine the bearing of the star at the desired time he uses the bearing chart of the stars. He makes a tabulation of the known data as follows:

Time = 0400 (Standard)
Date = 20 September
Latitude = 15° South
Longitude = 60° 28′ West

*c.* ~~To determine the local civil time he uses table I.~~

see c/ ~~Standard Time (60° zone) = 0400~~

~~60° + 15 = 4 correction to Greenwich time = 0400~~

Greenwich is east of his position; the sun passes Greenwich before it does his position, so Greenwich must have a later time.

| | | |
|---|---|---|
| Standard time | = | 0400 |
| Correction to Greenwich time | = | +0400 |
| Greenwich Civil Time | = | 0800 |

From table I:

| | | |
|---|---|---|
| 60° | = | 4 hr. 00 min. |
| 28′ = $1^{m}\ 52^{s}$ | = | 02 min. |
| | | 4 hr. 02 min. |

| | | |
|---|---|---|
| Correction to local civil time | = | −0402 |
| Local civil time | = | 0358 |

*d.* Using the local civil time 0358 and date 20 September, enter the chart on line *A* and

| Connect | On line | To | On line | Read | On line |
|---|---|---|---|---|---|
| 0358 | *A* | Sept. 20 | C | 03:47 | *B* |
| 0347 | D | Fomalhaut | *F* | 73° W | *E* |
| Fomalhaut | *G* | 73° | *J* | *M* = 27° | *H* |

in Southern Hemisphere using Southern Star add latitude 15° to *M* (27°) for line *K*. 15 + 27 = 42°.

| | | | | | |
|---|---|---|---|---|---|
| 42° | *K* | M = 27° | *M* | *P* = 46.5 | *L* |
| 46.5 | *L* | LHA = 73° | *O* | 63° | *N* |

*e.* The bearing is under 90° because the latitude was added to reference No. *M* and the sum was under 90° (see rules on line *N*). The bearing is from the south as the position is in the Southern Hemisphere. The bearing is toward the west as indicated on line *E*.

*f.* Therefore, the bearing of the star is south 63° west according to the chart. (True bearing according to Hydrographic Office Publication No. 214 is S 63° 14′ W.)

*Table III. Apparent places of 23 main stars for the period 1944–1948*
(In right ascension and declination)

| | ALPHERATZ α of Andromeda Mag. 2.2 | | DENEB KAITOS β of Cetus Mag. 2.2 | | ACHERNAR α of Eridanus Mag. 0.6 | | ALDEBARAN α of Taurus Mag. 1.1 | | RIGEL β of Orion Mag. 0.3 | | CAPELLA α of Auriga Mag. 0.2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1944 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $0^h\ 05.5^m$ | +28 46.9 | $0^h\ 40.8^m$ | —18 17.8 | $1^h\ 35.6^m$ | —57 31.7 | $4^h\ 32.7^m$ | +16 23.8 | $5^h\ 11.8^m$ | —8 16.0 | $5^h\ 12.5^m$ | +45 56.6 |
| Feb. | | +28 46.9 | | —18 17.8 | | —57 31.7 | | +16 23.8 | | —8 16.1 | | +45 56.6 |
| Mar. | | +28 46.8 | | —18 17.8 | | —57 31.6 | | +16 23.8 | | —8 16.2 | | +45 56.7 |
| Apr. | | +28 46.7 | | —18 17.7 | | —57 31.5 | | +16 23.8 | | —8 16.1 | | +45 56.6 |
| May | | +28 46.7 | | —18 17.6 | | —57 31.3 | | +16 23.8 | | —8 16.1 | | +45 56.6 |
| June | | +28 46.7 | | —18 17.5 | | —57 31.1 | | +16 23.8 | | —8 16.0 | | +45 56.5 |
| July | | +28 46.8 | | —18 17.4 | | —57 31.0 | | +16 23.8 | | —8 15.9 | | +45 56.5 |
| Aug. | | +28 46.9 | | —18 17.3 | | —57 30.9 | | +16 23.9 | | —8 15.8 | | +45 56.4 |
| Sep. | | +28 47.1 | | —18 17.3 | | —57 30.9 | | +16 23.9 | | —8 15.8 | | +45 56.4 |
| Oct. | | +28 47.2 | | —18 17.3 | | —57 31.0 | | +16 24.0 | | —8 15.8 | | +45 56.4 |
| Nov. | | +28 47.3 | | —18 17.4 | | —57 31.2 | | +16 24.0 | | —8 15.8 | | +45 56.5 |
| Dec. | | +28 47.3 | | —18 17.4 | | —57 31.3 | | +16 24.0 | | —8 15.9 | | +45 56.5 |
| 1945 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $0^h\ 05.5^m$ | +28 47.2 | $0^h\ 40.8^m$ | —18 17.5 | $1^h\ 35.7^m$ | —57 31.3 | $4^h\ 32.7^m$ | +16 24.0 | $5^h\ 11.9^m$ | —8 15.9 | $5^h\ 12.6^m$ | +45 56.7 |
| Feb. | | +28 47.2 | | —18 17.5 | | —57 31.3 | | +16 24.0 | | —8 16.0 | | +45 56.7 |
| Mar. | | +28 47.1 | | —18 17.5 | | —57 31.2 | | +16 24.0 | | —8 16.1 | | +45 56.8 |
| Apr. | | +28 47.0 | | —18 17.4 | | —57 31.1 | | +16 24.0 | | —8 16.0 | | +45 56.7 |
| May | | +28 47.0 | | —18 17.3 | | —57 30.9 | | +16 24.0 | | —8 16.0 | | +45 56.7 |
| June | | +28 47.0 | | —18 17.2 | | —57 30.7 | | +16 24.0 | | —8 15.9 | | +45 56.6 |
| July | | +28 47.1 | | —18 17.1 | | —57 30.6 | | +16 24.0 | | —8 15.8 | | +45 56.6 |
| Aug. | | +28 47.2 | | —18 17.0 | | —57 30.5 | | +16 24.1 | | —8 15.7 | | +45 56.5 |
| Sep. | | +28 47.4 | | —18 17.0 | | —57 30.5 | | +16 24.1 | | —8 15.7 | | +45 56.5 |
| Oct. | | +28 47.5 | | —18 17.0 | | —57 30.6 | | +16 24.2 | | —8 15.7 | | +45 56.5 |
| Nov. | | +28 47.6 | | —18 17.1 | | —57 30.8 | | +16 24.2 | | —8 15.7 | | +45 56.6 |
| Dec. | | +28 47.6 | | —18 17.1 | | —57 30.9 | | +16 24.2 | | —8 15.8 | | +45 56.6 |

*Table III. (Continued.)*

| | **BETELGEUX** α of Orion Var 0.1—1.2 | | **SIRIUS** α of Canis Major Mag. —1.6 | | **PROCYON** α of Canis Minor Mag. 0.5 | | **POLLUX** β of Gemini Mag. 1.2 | | **REGULUS** α of Leo Mag. 1.3 | | **DENEBOLA** β of Leo Mag. 2.2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1944 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $5^h\ 52.1^m$ | +7 23.8 | $6^h\ 42.7^m$ | —16 38.3 | $7^h\ 36.4^m$ | +5 22.2 | $7^h\ 41.9^m$ | +28 9.7 | $10^h\ 05.4^m$ | +12 14.5 | $11^h\ 46.2^m$ | +14 53.1 |
| Feb. | | +7 23.7 | | —16 38.4 | | +5 22.1 | | +28 9.7 | | +12 14.5 | | +14 53.0 |
| Mar. | | +7 23.7 | | —16 38.5 | | +5 22.1 | | +28 9.8 | | +12 14.4 | | +14 53.0 |
| Apr. | | +7 23.7 | | —16 38.5 | | +5 22.1 | | +28 9.8 | | +12 14.4 | | +14 53.0 |
| May | | +7 23.7 | | —16 38.5 | | +5 22.1 | | +28 9.8 | | +12 14.5 | | +14 53.1 |
| June | | +7 23.8 | | —16 38.4 | | +5 22.1 | | +28 9.8 | | +12 14.5 | | +14 53.1 |
| July | | +7 23.8 | | —16 38.3 | | +5 22.1 | | +28 9.8 | | +12 14.5 | | +14 53.1 |
| Aug. | | +7 23.9 | | —16 38.2 | | +5 22.2 | | +28 9.8 | | +12 14.5 | | +14 53.1 |
| Sep. | | +7 23.9 | | —16 38.2 | | +5 22.2 | | +28 9.7 | | +12 14.5 | | +14 53.1 |
| Oct. | | +7 23.9 | | —16 38.1 | | +5 22.2 | | +28 9.7 | | +12 14.5 | | +14 53.1 |
| Nov. | | +7 23.9 | | —16 38.2 | | +5 22.2 | | +28 9.6 | | +12 14.4 | | +14 53.0 |
| Dec. | | +7 23.8 | | —16 38.3 | | +5 22.1 | | +28 9.6 | | +12 14.3 | | +14 52.9 |
| 1945 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $5^h\ 52.2^m$ | +7 23.9 | $6^h\ 42.7^m$ | —16 38.4 | $7^h\ 36.4^m$ | +5 22.1 | $7^h\ 41.9^m$ | +28 9.6 | $10^h\ 05.4^m$ | +12 14.2 | $11^h\ 46.2^m$ | +14 52.8 |
| Feb. | | +7 23.8 | | —16 38.5 | | +5 22.0 | | +28 9.6 | | +12 14.2 | | +14 52.7 |
| Mar. | | +7 23.8 | | —16 38.6 | | +5 22.0 | | +28 9.7 | | +12 14.1 | | +14 52.7 |
| Apr. | | +7 23.8 | | —16 38.6 | | +5 22.0 | | +28 9.7 | | +12 14.1 | | +14 52.7 |
| May | | +7 23.8 | | —16 38.6 | | +5 22.0 | | +28 9.7 | | +12 14.2 | | +14 52.8 |
| June | | +7 23.9 | | —16 38.5 | | +5 22.0 | | +28 9.7 | | +12 14.2 | | +14 52.8 |
| July | | +7 23.9 | | —16 38.4 | | +5 22.0 | | +28 9.7 | | +12 14.2 | | +14 52.8 |
| Aug. | | +7 24.0 | | —16 38.3 | | +5 22.1 | | +28 9.7 | | +12 14.2 | | +14 52.8 |
| Sep. | | +7 24.0 | | —16 38.3 | | +5 22.1 | | +28 9.6 | | +12 14.2 | | +14 52.8 |
| Oct. | | +7 24.0 | | —16 38.2 | | +5 22.1 | | +28 9.6 | | +12 14.2 | | +14 52.8 |
| Nov. | | +7 24.0 | | —16 38.3 | | +5 22.1 | | +28 9.5 | | +12 14.1 | | +14 52.7 |
| Dec. | | +7 23.9 | | —16 38.4 | | +5 22.0 | | +28 9.5 | | +12 14.0 | | +14 52.6 |

*Table III. (Continued.)*

| | ACRUX α of Crux Mag. 1.1 | | SPICA α of Virgo Mag. 1.2 | | ARCTURUS α of Bootes Mag. 0.2 | | RIGEL KENT α of Centaurus Mag. 0.3 | | ANTARES α of Scorpio Mag. 1.2 | | VEGA α of Lyra Mag. 0.1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1944 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $12^h\ 23.5^m$ | —62 46.9 | $13^h\ 22.2^m$ | —10 52.1 | $14^h\ 13.1^m$ | +19 28.4 | $14^h\ 35.8^m$ | —60 35.9 | $16^h\ 26.0^m$ | —26 18.4 | $18^h\ 35.0^m$ | +38 43.9 |
| Feb. | | —62 47.0 | | —10 52.2 | | +19 28.3 | | —60 36.0 | | —26 18.5 | | +38 43.7 |
| Mar. | | —62 47.2 | | —10 52.2 | | +19 28.2 | | —60 36.1 | | —26 18.5 | | +38 43.6 |
| Apr. | | —62 47.4 | | —10 52.3 | | +19 28.3 | | —60 36.2 | | —26 18.5 | | +38 43.6 |
| May | | —62 47.5 | | —10 52.3 | | +19 28.3 | | —60 36.4 | | —26 18.6 | | +38 43.7 |
| June | | —62 47.6 | | —10 52.3 | | +19 28.4 | | —60 36.5 | | —26 18.6 | | +38 43.8 |
| July | | —62 47.7 | | —10 52.3 | | +19 28.5 | | —60 36.6 | | —26 18.6 | | +38 43.9 |
| Aug. | | —62 47.6 | | —10 52.3 | | +19 28.5 | | —60 36.6 | | —26 18.6 | | +38 44.1 |
| Sep. | | —62 47.5 | | —10 52.2 | | +19 28.5 | | —60 36.6 | | —26 18.6 | | +38 44.2 |
| Oct. | | —62 47.4 | | —10 52.2 | | +19 28.4 | | —60 36.5 | | —26 18.6 | | +38 44.2 |
| Nov. | | —62 47.3 | | —10 52.2 | | +19 28.3 | | —60 36.3 | | —26 18.6 | | +38 44.2 |
| Dec. | | —62 47.2 | | —10 52.3 | | +19 28.2 | | —60 36.2 | | —26 18.6 | | +38 44.1 |
| 1945 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $12^h\ 23.5^m$ | —62 47.3 | $13^h\ 22.3^m$ | —10 52.4 | $14^h\ 13.1^m$ | +19 28.1 | $14^h\ 35.8^m$ | —60 36.2 | $16^h\ 26.0^m$ | —26 18.6 | $18^h\ 35.1^m$ | +38 43.9 |
| Feb. | | —62 47.4 | | —10 52.5 | | +19 28.0 | | —60 36.3 | | —26 18.7 | | +38 43.7 |
| Mar. | | —62 47.6 | | —10 52.5 | | +19 27.9 | | —60 36.4 | | —26 18.7 | | +38 43.6 |
| Apr. | | —62 47.8 | | —10 52.6 | | +19 28.0 | | —60 36.5 | | —26 18.7 | | +38 43.6 |
| May | | —62 47.9 | | —10 52.6 | | +19 28.0 | | —60 36.7 | | —26 18.8 | | +38 43.7 |
| June | | —62 48.0 | | —10 52.6 | | +19 28.1 | | —60 36.8 | | —26 18.8 | | +38 43.8 |
| July | | —62 48.1 | | —10 52.6 | | +19 28.2 | | —60 36.9 | | —26 18.8 | | +38 43.9 |
| Aug. | | —62 48.0 | | —10 52.6 | | +19 28.2 | | —60 36.9 | | —26 18.8 | | +38 44.1 |
| Sep. | | —62 47.9 | | —10 52.5 | | +19 28.2 | | —60 36 9 | | —26 18.8 | | +38 44.2 |
| Oct. | | —62 47.8 | | —10 52.5 | | +19 28.1 | | —60 36.8 | | —26 18.8 | | +38 44.2 |
| Nov. | | —62 47.7 | | —10 52.5 | | +19 28.0 | | —60 36.6 | | —26 18.8 | | +38 44.2 |
| Dec. | | —62 47.6 | | —10 52.6 | | +19 27.9 | | —60 36.5 | | —26 18.8 | | +38 44.1 |

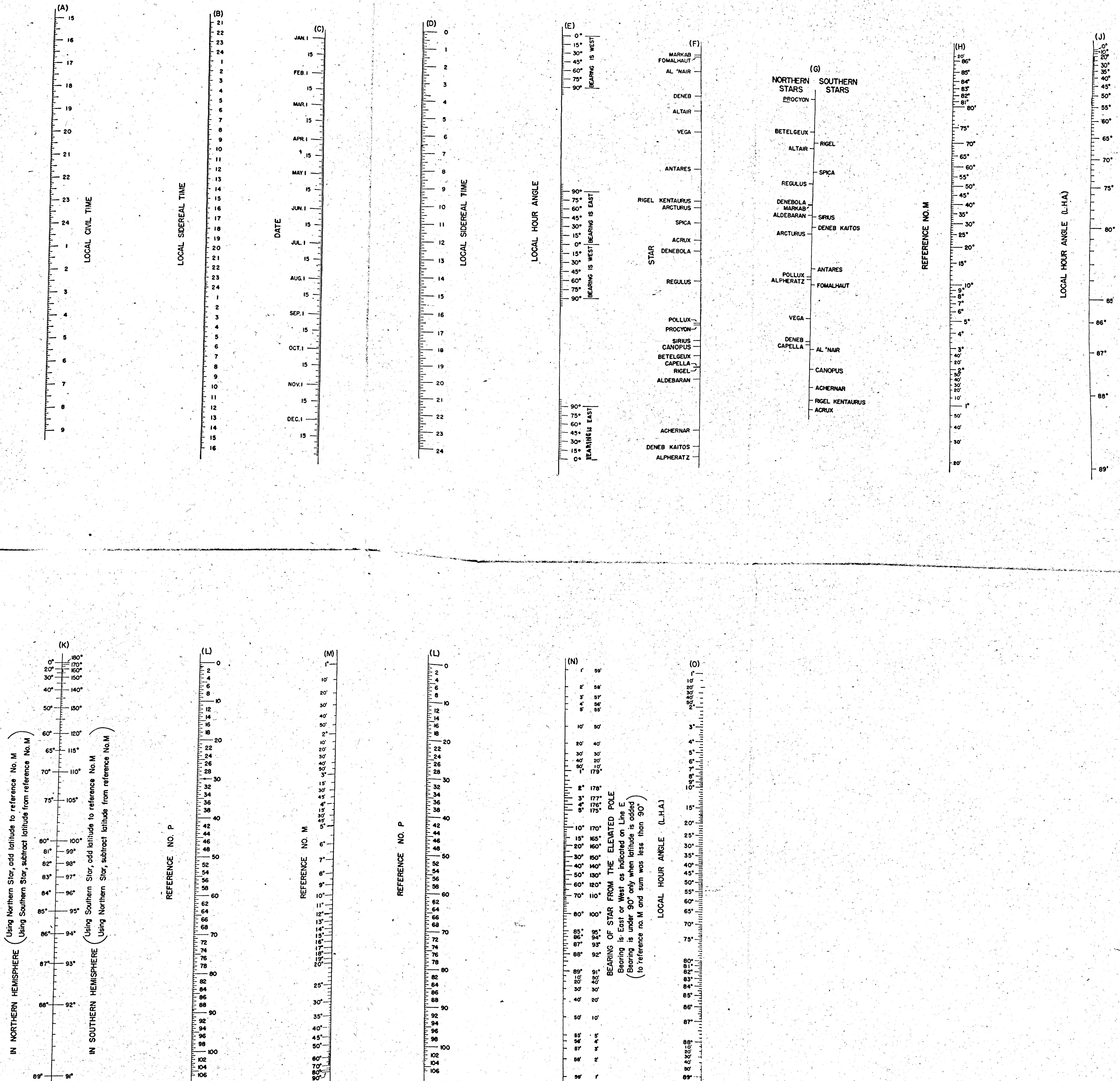



Chart II. Bearing chart of the stars

Table III. (Continued.)

| | ALTAIR α of Aquila Mag. 0.9 | | DENEB α of Cygnus Mag. 1.3 | | AL NA'IR α of Grus Mag. 2.2 | | FOMALHAUT α of Piscis Austr Mag. 1.3 | | MARKAB α of Pegasus Mag. 2.6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1944 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $19^h\ 48.0^m$ | +8 43.2 | $20^h\ 39.5^m$ | +45 4.9 | $22^h\ 04.7^m$ | —47 14.2 | $22^h\ 54.5^m$ | —29 55.5 | $23^h\ 01.9^m$ | +14 54.2 |
| Feb. | | +8 43.1 | | +45 4.8 | | —47 14.1 | | —29 55.4 | | +14 54.1 |
| Mar. | | +8 43.1 | | +45 4.6 | | —47 14.0 | | —29 55.4 | | +14 54.0 |
| Apr. | | +8 43.1 | | +45 4.6 | | —47 13.9 | | —29 55.3 | | +14 54.0 |
| May | | +8 43.1 | | +45 4.6 | | —47 13.8 | | —29 55.2 | | +14 54.0 |
| June | | +8 43.2 | | +45 4.7 | | —47 13.7 | | —29 55.0 | | +14 54.1 |
| July | | +8 43.3 | | +45 4.8 | | —47 13.6 | | —29 55.0 | | +14 54.2 |
| Aug. | | +8 43.4 | | +45 5.0 | | —47 13.7 | | —29 54.9 | | +14 54.3 |
| Sep. | | +8 43.5 | | +45 5.1 | | —47 13.7 | | —29 55.0 | | +14 54.4 |
| Oct. | | +8 43.5 | | +45 5.2 | | —47 13.8 | | —29 55.0 | | +14 54.5 |
| Nov. | | +8 43.5 | | +45 5.3 | | —47 13.9 | | —29 55.1 | | +14 54.5 |
| Dec. | | +8 43.4 | | +45 5.2 | | —47 13.9 | | —29 55.1 | | +14 54.5 |
| 1945 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $19^h\ 48.1^m$ | +8 43.3 | $20^h\ 39.5^m$ | +45 5.0 | $22^h\ 04.8^m$ | —47 14.0 | $22^h\ 54.6^m$ | —29 55.2 | $23^h\ 02.0^m$ | +14 54.5 |
| Feb. | | +8 43.2 | | +45 4.9 | | —47 13.9 | | —29 55.1 | | +14 54.4 |
| Mar. | | +8 43.2 | | +45 4.7 | | —47 13.8 | | —29 55.1 | | +14 54.3 |
| Apr. | | +8 43.2 | | +45 4.7 | | —47 13.7 | | —29 55.0 | | +14 54.3 |
| May | | +8 43.2 | | +45 4.7 | | —47 13.6 | | —29 54.9 | | +14 54.3 |
| June | | +8 43.3 | | +45 4.8 | | —47 13.5 | | —29 54.7 | | +14 54.4 |
| July | | +8 43.4 | | +45 4.9 | | —47 13.4 | | —29 54.7 | | +14 54.5 |
| Aug. | | +8 43.5 | | +45 5.1 | | —47 13.5 | | —29 54.6 | | +14 54.6 |
| Sep. | | +8 43.6 | | +45 5.2 | | —47 13.5 | | —29 54.7 | | +14 54.7 |
| Oct. | | +8 43.6 | | +45 5.3 | | —47 13.6 | | —29 54.7 | | +14 54.8 |
| Nov. | | +8 43.6 | | +45 5.4 | | —47 13.7 | | —29 54.8 | | +14 54.8 |
| Dec. | | +8 43.5 | | +45 5.3 | | —47 13.7 | | —29 54.8 | | +14 54.8 |

*Table III. (Continued.)*

| | ALPHERATZ α of Andromeda Mag. 2.2 | | DENEB KAITOS β of Cetus Mag. 2.2 | | ACHERNAR α of Eridanus Mag. 0.6 | | ALDEBARAN α of Taurus Mag. 1.1 | | RIGEL β of Orion Mag. 0.3 | | CAPELLA α of Auriga Mag. 0.2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1946 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | | +28 47.5 | | —18 17.2 | | —57 31.0 | | +16 24.1 | | —8 15.8 | | +45 56.8 |
| Feb. | | +28 47.5 | | —18 17.2 | | —57 31.0 | | +16 24.1 | | —8 15.9 | | +45 56.8 |
| Mar. | | +28 47.4 | | —18 17.2 | | —57 30.9 | | +16 24.1 | | —8 16.0 | | +45 56.9 |
| Apr. | | +28 47.3 | | —18 17.1 | | —57 30.8 | | +16 24.1 | | —8 15.9 | | +45 56.8 |
| May | | +28 47.3 | | —18 17.0 | | —57 30.6 | | +16 24.1 | | —8 15.9 | | +45 56.8 |
| June | $0^h\ 05.6^m$ | +28 47.3 | $0^h\ 40.9^m$ | —18 16.9 | $1^h\ 35.7^m$ | —57 30.4 | $4^h\ 32.8^m$ | +16 24.1 | $5^h\ 11.9^m$ | —8 15.8 | $5^h\ 12.7^m$ | +45 56.7 |
| July | | +28 47.4 | | —18 16.8 | | —57 30.3 | | +16 24.1 | | —8 15.7 | | +45 56.7 |
| Aug. | | +28 47.5 | | —18 16.7 | | —57 30.2 | | +16 24.2 | | —8 15.6 | | +45 56.6 |
| Sep. | | +28 47.7 | | —18 16.7 | | —57 30.2 | | +16 24.2 | | —8 15.6 | | +45 56.6 |
| Oct. | | +28 47.8 | | —18 16.7 | | —57 30.3 | | +16 24.3 | | —8 15.6 | | +45 56.6 |
| Nov. | | +28 47.9 | | —18 16.8 | | —57 30.5 | | +16 24.3 | | —8 15.6 | | +45 56.7 |
| Dec. | | +28 47.9 | | —18 16.8 | | —57 30.6 | | +16 24.3 | | —8 15.7 | | +45 56.7 |
| 1947 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | | +28 47.9 | | —18 16.8 | | —57 30.7 | | +16 24.3 | | —8 15.6 | | +45 56.9 |
| Feb. | | +28 47.9 | | —18 16.8 | | —57 30.7 | | +16 24.3 | | —8 15.7 | | +45 56.9 |
| Mar. | | +28 47.8 | | —18 16.8 | | —57 30.6 | | +16 24.3 | | —8 15.8 | | +45 57.0 |
| Apr. | | +28 47.7 | | —18 16.7 | | —57 30.5 | | +16 24.3 | | —8 15.7 | | +45 56.9 |
| May | | +28 47.7 | | —18 16.6 | | —57 30.3 | | +16 24.3 | | —8 15.7 | | +45 56.9 |
| June | $0^h\ 05.6^m$ | +28 47.7 | $0^h\ 40.9^m$ | —18 16.5 | $1^h\ 35.7^m$ | —57 30.1 | $4^h\ 32.9^m$ | +16 24.3 | $5^h\ 12.0^m$ | —8 15.6 | $5^h\ 12.7^m$ | +45 56.8 |
| July | | +28 47.8 | | —18 16.4 | | —57 30.0 | | +16 24.3 | | —8 15.5 | | +45 56.8 |
| Aug. | | +28 47.9 | | —18 16.3 | | —57 29.9 | | +16 24.4 | | —8 15.4 | | +45 56.7 |
| Sep. | | +28 48.1 | | —18 16.3 | | —57 29.9 | | +16 24.4 | | —8 15.4 | | +45 56.7 |
| Oct. | | +28 48.2 | | —18 16.3 | | —57 30.0 | | +16 24.5 | | —8 15.4 | | +45 56.7 |
| Nov. | | +28 48.3 | | —18 16.4 | | —57 30.2 | | +16 24.5 | | —8 15.4 | | +45 56.8 |
| Dec. | | +28 48.3 | | —18 16.4 | | —57 30.3 | | +16 24.5 | | —8 15.5 | | +45 56.8 |
| 1948 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | | +28 48.2 | | —18 16.5 | | —57 30.3 | | +16 24.5 | | —8 15.5 | | +45 56.9 |
| Feb. | | +28 48.2 | | —18 16.5 | | —57 30.3 | | +16 24.5 | | —8 15.6 | | +45 56.9 |
| Mar. | | +28 48.1 | | —18 16.5 | | —57 30.2 | | +16 24.5 | | —8 15.7 | | +45 57.0 |
| Apr. | | +28 48.0 | | —18 16.4 | | —57 30.1 | | +16 24.5 | | —8 15.6 | | +45 56.9 |
| May | | +28 48.0 | | —18 16.3 | | —57 29.9 | | +16 24.5 | | —8 15.6 | | +45 56.9 |
| June | $0^h\ 05.7^m$ | +28 48.0 | $0^h\ 41.0^m$ | —18 16.2 | $1^h\ 35.8^m$ | —57 29.7 | $4^h\ 32.9^m$ | +16 24.5 | $5^h\ 12.0^m$ | —8 15.5 | $5^h\ 12.8^m$ | +45 56.8 |
| July | | +28 48.1 | | —18 16.1 | | —57 29.6 | | +16 24.5 | | —8 15.4 | | +45 56.8 |
| Aug. | | +28 48.2 | | —18 16.0 | | —57 29.5 | | +16 24.6 | | —8 15.3 | | +45 56.7 |
| Sep. | | +28 48.4 | | —18 16.0 | | —57 29.5 | | +16 24.6 | | —8 15.3 | | +45 56.7 |
| Oct. | | +28 48.5 | | —18 16.0 | | —57 29.6 | | +16 24.7 | | —8 15.3 | | +45 56.7 |
| Nov. | | +28 48.6 | | —18 16.1 | | —57 29.8 | | +16 24.7 | | —8 15.3 | | +45 56.8 |
| Dec. | | +28 48.6 | | —18 16.1 | | —57 29.9 | | +16 24.7 | | —8 15.4 | | +45 56.8 |

*Table III. (Continued.)*

| | BETELGEUX α of Orion Var 0.1—1.2 | | SIRIUS α of Canis Major Mag. —1.6 | | PROCYON α of Canis Minor Mag. 0.5 | | POLLUX β of Gemini Mag. 1.2 | | REGULUS α of Leo Mag. 1.3 | | DENEBOLA β of Leo Mag. 2.2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1946 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $5^h\ 52.2^m$ | +7 23.9 | $6^h\ 42.8^m$ | —16 38.4 | $7^h\ 36.5^m$ | +5 22.0 | $7^h\ 42.0^m$ | +28 9.5 | $10^h\ 05.5^m$ | +12 13.9 | $11^h\ 46.3^m$ | +14 52.4 |
| Feb. | | +7 23.8 | | —16 38.5 | | +5 21.9 | | +28 9.5 | | +12 13.9 | | +14 52.3 |
| Mar. | | +7 23.8 | | —16 38.6 | | +5 21.9 | | +28 9.6 | | +12 13.8 | | +14 52.3 |
| Apr. | | +7 23.8 | | —16 38.6 | | +5 21.9 | | +28 9.6 | | +12 13.8 | | +14 52.3 |
| May | | +7 23.8 | | —16 38.6 | | +5 21.9 | | +28 9.6 | | +12 13.9 | | +14 52.4 |
| June | | +7 23.9 | | —16 38.5 | | +5 21.9 | | +28 9.6 | | +12 13.9 | | +14 52.4 |
| July | | +7 23.9 | | —16 38.4 | | +5 21.9 | | +28 9.6 | | +12 13.9 | | +14 52.4 |
| Aug. | | +7 24.0 | | —16 38.3 | | +5 22.0 | | +28 9.6 | | +12 13.9 | | +14 52.4 |
| Sep. | | +7 24.0 | | —16 38.3 | | +5 22.0 | | +28 9.5 | | +12 13.9 | | +14 52.4 |
| Oct. | | +7 24.0 | | —16 38.2 | | +5 22.0 | | +28 9.5 | | +12 13.9 | | +14 52.4 |
| Nov. | | +7 24.0 | | —16 38.3 | | +5 22.0 | | +28 9.4 | | +12 13.8 | | +14 52.3 |
| Dec. | | +7 23.9 | | —16 38.4 | | +5 21.9 | | +28 9.4 | | +12 13.7 | | +14 52.2 |
| 1947 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $5^h\ 52.3^m$ | +7 24.0 | $6^h\ 42.8^m$ | —16 38.4 | $7^h\ 36.5^m$ | +5 21.8 | $7^h\ 42.1^m$ | +28 9.4 | $10^h\ 05.5^m$ | +12 13.6 | $11^h\ 46.3^m$ | +14 52.1 |
| Feb. | | +7 23.9 | | —16 38.5 | | +5 21.7 | | +28 9.4 | | +12 13.6 | | +14 52.0 |
| Mar. | | +7 23.9 | | —16 38.6 | | +5 21.7 | | +28 9.5 | | +12 13.5 | | +14 52.0 |
| Apr. | | +7 23.9 | | —16 38.6 | | +5 21.7 | | +28 9.5 | | +12 13.5 | | +14 52.0 |
| May | | +7 23.9 | | —16 38.6 | | +5 21.7 | | +28 9.5 | | +12 13.6 | | +14 52.1 |
| June | | +7 24.0 | | —16 38.5 | | +5 21.7 | | +28 9.5 | | +12 13.6 | | +14 52.1 |
| July | | +7 24.0 | | —16 38.4 | | +5 21.7 | | +28 9.5 | | +12 13.6 | | +14 52.1 |
| Aug. | | +7 24.1 | | —16 38.3 | | +5 21.8 | | +28 9.5 | | +12 13.6 | | +14 52.1 |
| Sep. | | +7 24.1 | | —16 38.3 | | +5 21.8 | | +28 9.4 | | +12 13.6 | | +14 52.1 |
| Oct. | | +7 24.1 | | —16 38.2 | | +5 21.8 | | +28 9.4 | | +12 13.6 | | +14 52.1 |
| Nov. | | +7 24.1 | | —16 38.3 | | +5 21.8 | | +28 9.3 | | +12 13.5 | | +14 52.0 |
| Dec. | | +7 24.0 | | —16 38.4 | | +5 21.7 | | +28 9.3 | | +12 13.4 | | +14 51.9 |
| 1948 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $5^h\ 52.3^m$ | +7 24.1 | $6^h\ 42.8^m$ | —16 38.5 | $7^h\ 36.6^m$ | +5 21.7 | $7^h\ 42.1^m$ | +28 9.2 | $10^h\ 05.6^m$ | +12 13.3 | $11^h\ 46.4^m$ | +14 51.7 |
| Feb. | | +7 24.0 | | —16 38.6 | | +5 21.6 | | +28 9.2 | | +12 13.3 | | +14 51.6 |
| Mar. | | +7 24.0 | | —16 38.7 | | +5 21.6 | | +28 9.3 | | +12 13.2 | | +14 51.6 |
| Apr. | | +7 24.0 | | —16 38.7 | | +5 21.6 | | +28 9.3 | | +12 13.2 | | +14 51.6 |
| May | | +7 24.0 | | —16 38.7 | | +5 21.6 | | +28 9.3 | | +12 13.3 | | +14 51.7 |
| June | | +7 24.1 | | —16 38.6 | | +5 21.6 | | +28 9.3 | | +12 13.3 | | +14 51.7 |
| July | | +7 24.1 | | —16 38.5 | | +5 21.6 | | +28 9.3 | | +12 13.3 | | +14 51.7 |
| Aug. | | +7 24.2 | | —16 38.4 | | +5 21.7 | | +28 9.3 | | +12 13.3 | | +14 51.7 |
| Sep. | | +7 24.2 | | —16 38.4 | | +5 21.7 | | +28 9.2 | | +12 13.3 | | +14 51.7 |
| Oct. | | +7 24.2 | | —16 38.3 | | +5 21.7 | | +28 9.2 | | +12 13.3 | | +14 51.7 |
| Nov. | | +7 24.2 | | —16 38.4 | | +5 21.7 | | +28 9.1 | | +12 13.2 | | +14 51.6 |
| Dec. | | +7 24.1 | | —16 38.5 | | +5 21.6 | | +28 9.1 | | +12 13.1 | | +14 51.5 |

*Table III. (Continued.)*

| Date | ACRUX α of Crux Mag. 1.1 Ra. | ACRUX Decl. | SPICA α of Virgo Mag. 1.2 Ra. | SPICA Decl. | ARCTURUS α of Bootes Mag. 0.2 Ra. | ARCTURUS Decl. | RIGEL KENT α of Centaurus Mag. 0.3 Ra. | RIGEL KENT Decl. | ANTARES α of Scorpio Mag. 1.2 Ra. | ANTARES Decl. | VEGA α of Lyra Mag. 0.1 Ra. | VEGA Decl. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1946 | $12^h\ 23.6^m$ | ° ′ | $13^h\ 22.3^m$ | ° ′ | $14^h\ 13.2^m$ | ° ′ | $14^h\ 35.9^m$ | ° ′ | $16^h\ 26.1^m$ | ° ′ | $18^h\ 35.1^m$ | ° ′ |
| Jan. | | —62 47.6 | | —10 52.7 | | +19 27.7 | | —60 36.5 | | —26 18.7 | | +38 43.9 |
| Feb. | | —62 47.7 | | —10 52.8 | | +19 27.6 | | —60 36.6 | | —26 18.8 | | +38 43.7 |
| Mar. | | —62 47.9 | | —10 52.8 | | +19 27.5 | | —60 36.7 | | —26 18.8 | | +38 43.6 |
| Apr. | | —62 48.1 | | —10 52.9 | | +19 27.6 | | —60 36.8 | | —26 18.8 | | +38 43.6 |
| May | | —62 48.2 | | —10 52.9 | | +19 27.6 | | —60 37.0 | | —26 18.9 | | +38 43.7 |
| June | | —62 48.3 | | —10 52.9 | | +19 27.7 | | —60 37.1 | | —26 18.9 | | +38 43.8 |
| July | | —62 48.4 | | —10 52.9 | | +19 27.8 | | —60 37.2 | | —26 18.9 | | +38 43.9 |
| Aug. | | —62 48.3 | | —10 52.9 | | +19 27.8 | | —60 37.2 | | —26 18.9 | | +38 44.1 |
| Sep. | | —62 48.2 | | —10 52.8 | | +19 27.8 | | —60 37.2 | | —26 18.9 | | +38 44.2 |
| Oct. | | —62 48.1 | | —10 52.8 | | +19 27.7 | | —60 37.1 | | —26 18.9 | | +38 44.2 |
| Nov. | | —62 48.0 | | —10 52.8 | | +19 27.6 | | —60 36.9 | | —26 18.9 | | +38 44.2 |
| Dec. | | —62 47.9 | | —10 52.9 | | +19 27.5 | | —60 36.8 | | —26 18.9 | | +38 44.1 |
| 1947 | $12^h\ 23.6^m$ | ° ′ | $13^h\ 22.4^m$ | ° ′ | $14^h\ 13.2^m$ | ° ′ | $14^h\ 36.0^m$ | ° ′ | $16^h\ 26.1^m$ | ° ′ | $18^h\ 35.1^m$ | ° ′ |
| Jan. | | —62 48.0 | | —10 53.1 | | +19 27.4 | | —60 36.7 | | —26 18.9 | | +38 43.9 |
| Feb. | | —62 48.1 | | —10 53.2 | | +19 27.3 | | —60 36.8 | | —26 19.0 | | +38 43.7 |
| Mar. | | —62 48.3 | | —10 53.2 | | +19 27.2 | | —60 36.9 | | —26 19.0 | | +38 43.6 |
| Apr. | | —62 48.5 | | —10 53.3 | | +19 27.3 | | —60 37.0 | | —26 19.0 | | +38 43.6 |
| May | | —62 48.6 | | —10 53.3 | | +19 27.3 | | —60 37.2 | | —26 19.1 | | +38 43.7 |
| June | | —62 48.7 | | —10 53.3 | | +19 27.4 | | —60 37.3 | | —26 19.1 | | +38 43.8 |
| July | | —62 48.8 | | —10 53.3 | | +19 27.5 | | —60 37.4 | | —26 19.1 | | +38 43.9 |
| Aug. | | —62 48.7 | | —10 53.3 | | +19 27.5 | | —60 37.4 | | —26 19.1 | | +38 44.1 |
| Sep. | | —62 48.6 | | —10 53.2 | | +19 27.5 | | —60 37.4 | | —26 19.1 | | +38 44.2 |
| Oct. | | —62 48.5 | | —10 53.2 | | +19 27.4 | | —60 37.3 | | —26 19.1 | | +38 44.2 |
| Nov. | | —62 48.4 | | —10 53.2 | | +19 27.3 | | —60 37.1 | | —26 19.1 | | +38 44.2 |
| Dec. | | —62 48.3 | | —10 53.3 | | +19 27.2 | | —60 37.0 | | —26 19.1 | | +38 44.1 |
| 1948 | $12^h\ 23.7^m$ | ° ′ | $13^h\ 22.4^m$ | ° ′ | $14^h\ 13.3^m$ | ° ′ | $14^h\ 36.0^m$ | ° ′ | $16^h\ 26.2^m$ | ° ′ | $18^h\ 35.2^m$ | ° ′ |
| Jan. | | —62 48.3 | | —10 53.4 | | +19 27.0 | | —60 37.0 | | —26 19.1 | | +38 43.9 |
| Feb. | | —62 48.4 | | —10 53.5 | | +19 26.9 | | —60 37.1 | | —26 19.2 | | +38 43.7 |
| Mar. | | —62 48.6 | | —10 53.5 | | +19 26.8 | | —60 37.2 | | —26 19.2 | | +38 43.6 |
| Apr. | | —62 48.8 | | —10 53.6 | | +19 26.9 | | —60 37.3 | | —26 19.2 | | +38 43.6 |
| May | | —62 48.9 | | —10 53.6 | | +19 26.9 | | —60 37.5 | | —26 19.3 | | +38 43.7 |
| June | | —62 49.0 | | —10 53.6 | | +19 27.0 | | —60 37.6 | | —26 19.3 | | +38 43.8 |
| July | | —62 49.1 | | —10 53.6 | | +19 27.1 | | —60 37.7 | | —26 19.3 | | +38 43.9 |
| Aug. | | —62 49.0 | | —10 53.6 | | +19 27.1 | | —60 37.7 | | —26 19.3 | | +38 44.1 |
| Sep. | | —62 48.9 | | —10 53.5 | | +19 27.1 | | —60 37.7 | | —26 19.3 | | +38 44.2 |
| Oct. | | —62 48.8 | | —10 53.5 | | +19 27.0 | | —60 37.6 | | —26 19.3 | | +38 44.2 |
| Nov. | | —62 48.7 | | —10 53.5 | | +19 26.9 | | —60 37.4 | | —26 19.3 | | +38 44.2 |
| Dec. | | —62 48.6 | | —10 53.6 | | +19 26.8 | | —60 37.3 | | —26 19.3 | | +38 44.1 |

*Table III. (Continued.)*

| | ALTAIR α of Aquila Mag. 0.9 | | DENEB α of Cygnus Mag. 1.3 | | AL NA'IR α of Grus Mag. 2.2 | | FOMALHAUT α of Piscis Austr Mag. 1.3 | | MARKAB α of Pegasus Mag. 2.6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. | Ra. | Decl. |
| 1946 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $19^h\ 48.1^m$ | +8 43.4 | $20^h\ 39.6^m$ | +45 5.2 | $22^h\ 04.8^m$ | −47 13.7 | $22^h\ 54.7^m$ | −29 54.8 | $23^h\ 02.1^m$ | +14 54.8 |
| Feb. | | +8 43.3 | | +45 5.1 | | −47 13.6 | | −29 54.7 | | +14 54.7 |
| Mar. | | +8 43.3 | | +45 4.9 | | −47 13.5 | | −29 54.7 | | +14 54.6 |
| Apr. | | +8 43.3 | | +45 4.9 | | −47 13.4 | | −29 54.6 | | +14 54.6 |
| May | | +8 43.3 | | +45 4.9 | | −47 13.3 | | −29 54.5 | | +14 54.6 |
| June | | +8 43.4 | | +45 5.0 | | −47 13.2 | | −29 54.3 | | +14 54.7 |
| July | | +8 43.5 | | +45 5.1 | | −47 13.1 | | −29 54.3 | | +14 54.8 |
| Aug. | | +8 43.6 | | +45 5.3 | | −47 13.2 | | −29 54.2 | | +14 54.9 |
| Sep. | | +8 43.7 | | +45 5.4 | | −47 13.2 | | −29 54 3 | | +14 55.0 |
| Oct. | | +8 43.7 | | +45 5.5 | | −47 13.3 | | −29 54.3 | | +14 55.1 |
| Nov. | | +8 43.7 | | +45 5.6 | | −47 13.4 | | −29 54.4 | | +14 55.1 |
| Dec. | | +8 43.6 | | +45 5.5 | | −47 13.4 | | −29 54.4 | | +14 55.1 |
| 1947 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $19^h\ 48.2^m$ | +8 43.5 | $20^h\ 39.6^m$ | +45 5.4 | $22^h\ 04.9^m$ | −47 13.4 | $22^h\ 54.7^m$ | −29 54.5 | $23^h\ 02.1^m$ | +14 55.2 |
| Feb. | | +8 43.4 | | +45 5.3 | | −47 13.3 | | −29 54.4 | | +14 55.1 |
| Mar. | | +8 43.4 | | +45 5.1 | | −47 13.2 | | −29 54.4 | | +14 55.0 |
| Apr. | | +8 43.4 | | +45 5.1 | | −47 13.1 | | −29 54.3 | | +14 55.0 |
| May | | +8 43.4 | | +45 5.1 | | −47 13.0 | | −29 54.2 | | +14 55.0 |
| June | | +8 43.5 | | +45 5.2 | | −47 12.9 | | −29 54.0 | | +14 55.1 |
| July | | +8 43.6 | | +45 5.3 | | −47 12.8 | | −29 54.0 | | +14 55.2 |
| Aug. | | +8 43.7 | | +45 5.5 | | −47 12.9 | | −29 53.9 | | +14 55.3 |
| Sep. | | +8 43.8 | | +45 5.6 | | −47 12.9 | | −29 54.0 | | +14 55.4 |
| Oct. | | +8 43.8 | | +45 5.7 | | −47 13.0 | | −29 54.0 | | +14 55.5 |
| Nov. | | +8 43.8 | | +45 5.8 | | −47 13.1 | | −29 54.1 | | +14 55.5 |
| Dec. | | +8 43.7 | | +45 5.7 | | −47 13.1 | | −29 54.1 | | +14 55.5 |
| 1948 | | ° ′ | | ° ′ | | ° ′ | | ° ′ | | ° ′ |
| Jan. | $19^h\ 48.2^m$ | +8 43.6 | $20^h\ 39.6^m$ | +45 5.6 | $22^h\ 05.0^m$ | −47 13.1 | $22^h\ 54.8^m$ | −29 54.2 | $23^h\ 02.2^m$ | +14 55.5 |
| Feb. | | +8 43.5 | | +45 5.5 | | −47 13.0 | | −29 54.1 | | +14 55.4 |
| Mar. | | +8 43.5 | | +45 5.3 | | −47 12.9 | | −29 54.1 | | +14 55.3 |
| Apr. | | +8 43.5 | | +45 5.3 | | −47 12.8 | | −29 54.0 | | +14 55.3 |
| May | | +8 43.5 | | +45 5.3 | | −47 12.7 | | −29 53.9 | | +14 55.3 |
| June | | +8 43.6 | | +45 5.4 | | −47 12.6 | | −29 53.7 | | +14 55.4 |
| July | | +8 43.7 | | +45 5.5 | | −47 12.5 | | −29 53.7 | | +14 55.5 |
| Aug. | | +8 43.8 | | +45 5.7 | | −47 12.6 | | −29 53.6 | | +14 55.6 |
| Sep. | | +8 43.9 | | +45 5.8 | | −47 12.6 | | −29 53.7 | | +14 55.7 |
| Oct. | | +8 43.9 | | +45 5.9 | | −47 12.7 | | −29 53.7 | | +14 55.8 |
| Nov. | | +8 43.9 | | +45 6.0 | | −47 12.8 | | −29 53.8 | | +14 55.8 |
| Dec. | | +8 43.8 | | +45 5.9 | | −47 12.8 | | −29 53.8 | | +14 55.8 |

*Table IV. Azimuths of Polaris at maximum elongation for the years 1944–50*

| Latitude | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 |
|---|---|---|---|---|---|---|---|
| ° | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 10 | 1 1.1 | 1 0.8 | 1 0.5 | 1 0.1 | 0 59.8 | 0 59.5 | 0 59.1 |
| 11 | 1.3 | 1.0 | 0.7 | 0.3 | 0.0 | 59.8 | 59.3 |
| 12 | 1.6 | 1.2 | 0.9 | 0.6 | 0.2 | 59.9 | 59.5 |
| 13 | 1.8 | 1.5 | 1.1 | 0.8 | 0.5 | 1 0.1 | 59.8 |
| 14 | 2.1 | 1.7 | 1.4 | 1.0 | 0.7 | 0.4 | 1 0.0 |
| 15 | 2.3 | 2.0 | 1.7 | 1.3 | 1.0 | 0.6 | 0.3 |
| 16 | 2.6 | 2.3 | 2.0 | 1.6 | 1.3 | 0.9 | 0.6 |
| 17 | 3.0 | 2.6 | 2.3 | 1.9 | 1.6 | 1.2 | 0.9 |
| 18 | 3.3 | 3.0 | 2.6 | 2.3 | 1.9 | 1.6 | 1.2 |
| 19 | 3.7 | 3.3 | 3.0 | 2.6 | 2.3 | 1.9 | 1.6 |
| 20 | 4.1 | 3.7 | 3.4 | 3.0 | 2.7 | 2.3 | 2.0 |
| 21 | 4.5 | 4.1 | 3.8 | 3.4 | 3.1 | 2.7 | 2.4 |
| 22 | 4.9 | 4.6 | 4.2 | 3.9 | 3.5 | 3.2 | 2.8 |
| 23 | 5.4 | 5.1 | 4.7 | 4.3 | 4.0 | 3.6 | 3.3 |
| 24 | 5.9 | 5.5 | 5.1 | 4.8 | 4.5 | 4.1 | 3.8 |
| 25 | 1 6.4 | 1 6.1 | 1 5.7 | 1 5.3 | 1 5.0 | 1 4.6 | 1 4.2 |
| 26 | 7.0 | 6.6 | 6.3 | 5.9 | 5.5 | 5.1 | 4.8 |
| 27 | 7.5 | 7.2 | 6.8 | 6.5 | 6.1 | 5.7 | 5.3 |
| 28 | 8.2 | 7.8 | 7.4 | 7.1 | 6.7 | 6.3 | 5.9 |
| 29 | 8.8 | 8.5 | 8.1 | 7.7 | 7.3 | 6.9 | 6.5 |
| 30 | 9.5 | 9.1 | 8.8 | 8.4 | 8.0 | 7.6 | 7.2 |
| 31 | 10.2 | 9.9 | 9.5 | 9.1 | 8.7 | 8.3 | 7.9 |
| 32 | 11.0 | 10.6 | 10.2 | 9.8 | 9.4 | 9.0 | 8.6 |
| 33 | 11.8 | 11.4 | 11.0 | 10.6 | 10.2 | 9.8 | 9.4 |
| 34 | 12.6 | 12.2 | 11.8 | 11.4 | 11.0 | 10.6 | 10.2 |
| 35 | 13.5 | 13.1 | 12.7 | 12.3 | 11.9 | 11.5 | 11.1 |
| 36 | 14.4 | 14.0 | 13.6 | 13.2 | 12.8 | 12.4 | 11.9 |
| 37 | 15.4 | 15.0 | 14.6 | 14.1 | 13.7 | 13.3 | 12.9 |
| 38 | 16.4 | 16.0 | 15.6 | 15.1 | 14.7 | 14.3 | 13.9 |
| 39 | 17.4 | 17.0 | 16.6 | 16.2 | 15.8 | 15.3 | 14.9 |
| 40 | 18.6 | 18.2 | 17.7 | 17.3 | 16.9 | 16.4 | 16.0 |
| 41 | 19.7 | 19.3 | 18.9 | 18.5 | 18.0 | 17.6 | 17.1 |
| 42 | 21.0 | 20.6 | 20.1 | 19.7 | 19.2 | 18.8 | 18.3 |
| 43 | 22.3 | 21.9 | 21.4 | 21.0 | 20.5 | 20.0 | 19.6 |
| 44 | 23.7 | 23.2 | 22.8 | 22.3 | 21.9 | 21.4 | 20.9 |
| 45 | 25.1 | 24.7 | 24.2 | 23.7 | 23.3 | 22.8 | 22.3 |
| 46 | 26.6 | 26.2 | 25.7 | 25.2 | 24.8 | 24.8 | 23.8 |
| 47 | 28.3 | 27.8 | 27.3 | 26.8 | 26.3 | 25.8 | 25.3 |
| 48 | 30.0 | 29.5 | 29.0 | 28.5 | 28.0 | 27.5 | 27.0 |
| 49 | 31.7 | 31.5 | 30.8 | 30.3 | 29.8 | 29.2 | 28.7 |
| 50 | 1 33.6 | 1 33.2 | 1 32.6 | 1 32.1 | 1 31.6 | 1 31.1 | 1 30.6 |
| 51 | 35.7 | 35.2 | 34.6 | 34.1 | 33.6 | 33.1 | 32.5 |
| 52 | 37.8 | 37.3 | 36.8 | 36.2 | 35.7 | 35.1 | 34.5 |
| 53 | 40.0 | 39.7 | 39.0 | 38.4 | 37.9 | 37.3 | 36.8 |
| 54 | 42.4 | 41.9 | 41.3 | 40.8 | 40.2 | 39.6 | 39.1 |

*Table IV—Continued*

| Latitude | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 |
|---|---|---|---|---|---|---|---|
| ° | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 55 | 45.0 | 44.4 | 43.8 | 43.3 | 42.7 | 42.1 | 41.5 |
| 56 | 47.6 | 47.1 | 46.5 | 45.9 | 45.3 | 44.7 | 44.2 |
| 57 | 50.8 | 49.9 | 49.3 | 48.7 | 48.1 | 47.5 | 46.9 |
| 58 | 53.6 | 53.0 | 52.4 | 51.8 | 51.1 | 50.5 | 49.9 |
| 59 | 56.9 | 56.3 | 55.6 | 55.0 | 54.4 | 53.7 | 53.1 |
| 60 | 2 0.4 | 59.8 | 59.1 | 58.5 | 58.1 | 57.1 | 56.5 |

Corrections for middle of months

| For middle of | Correction, min. |
|---|---|
| January | —0.5 |
| February | —0.4 |
| March | —0.3 |
| April | —0.1 |
| May | +0.1 |
| June | +0.2 |
| July | +0.2 |
| August | +0.1 |
| September | —0.1 |
| October | —0.3 |
| November | —0.6 |
| December | —0.8 |

# APPENDIX II

# AIR DEFENSE GRID TABLES

*Lengths of basic grid and fifth division grid for each degree of latitude from 0° to 80°.*

| Latitude Degrees N or S | Latitude: 48′ Latitude in Miles | Latitude: 48′ Latitude in Yards | Latitude: 5th Division Grid in Yards | Longitude: 48′ Longitude in Miles | Longitude: 48′ Longitude in Yards | Longitude: 5th Division Grid in Yards |
|---|---|---|---|---|---|---|
| 0 | 54.963 | 96730 | 9673 | 55.338 | 97390 | 9739 |
| 1 | 54.963 | 96730 | 9673 | 55.330 | 97380 | 9738 |
| 2 | 54.964 | 96740 | 9674 | 55.304 | 97340 | 9734 |
| 3 | 54.965 | 96740 | 9674 | 55.262 | 97260 | 9726 |
| 4 | 54.966 | 96740 | 9674 | 55.204 | 97160 | 9716 |
| 5 | 54.968 | 96740 | 9674 | 55.129 | 97030 | 9703 |
| 6 | 54.970 | 96750 | 9675 | 55.036 | 96860 | 9686 |
| 7 | 54.972 | 96750 | 9675 | 54.928 | 96670 | 9667 |
| 8 | 54.974 | 96750 | 9675 | 54.803 | 96450 | 9645 |
| 9 | 54.977 | 96760 | 9676 | 54.661 | 96200 | 9620 |
| 10 | 54.980 | 96760 | 9676 | 54.503 | 95930 | 9593 |
| 11 | 54.984 | 96770 | 9677 | 54.328 | 95620 | 9562 |
| 12 | 54.987 | 96780 | 9678 | 54.136 | 95280 | 9528 |
| 13 | 54.991 | 96780 | 9678 | 53.928 | 94910 | 9491 |
| 14 | 54.995 | 96790 | 9679 | 53.705 | 94520 | 9452 |
| 15 | 55.001 | 96800 | 9680 | 53.464 | 94100 | 9410 |
| 16 | 55.006 | 96810 | 9681 | 53.208 | 93650 | 9365 |
| 17 | 55.011 | 96820 | 9682 | 52.935 | 93170 | 9317 |
| 18 | 55.017 | 96830 | 9683 | 52.646 | 92660 | 9266 |
| 19 | 55.022 | 96840 | 9684 | 52.342 | 92120 | 9212 |

| Latitude Degrees N or S | Latitude | | | Longitude | | |
|---|---|---|---|---|---|---|
| | 48′ Latitude in Miles | 48′ Latitude in Yards | 5th Division Grid in Yards | 48′ Longitude in Miles | 48′ Longitude in Yards | 5th Division Grid in Yards |
| 20 | 55.029 | 96850 | 9685 | 52.021 | 91560 | 9156 |
| 21 | 55.035 | 96860 | 9686 | 51.685 | 90970 | 9097 |
| 22 | 55.042 | 96870 | 9687 | 51.333 | 90350 | 9035 |
| 23 | 55.049 | 96890 | 9689 | 50.965 | 89700 | 8970 |
| 24 | 55.056 | 96900 | 9690 | 50.582 | 89020 | 8902 |
| 25 | 55.063 | 96910 | 9691 | 50.183 | 88320 | 8832 |
| 26 | 55.071 | 96920 | 9692 | 49.770 | 87600 | 8760 |
| 27 | 55.078 | 96940 | 9694 | 49.341 | 86840 | 8684 |
| 28 | 55.086 | 96950 | 9695 | 48.898 | 86060 | 8606 |
| 29 | 55.095 | 96970 | 9697 | 48.438 | 85250 | 8525 |
| 30 | 55.103 | 96980 | 9698 | 47.965 | 84420 | 8442 |
| 31 | 55.112 | 97000 | 9700 | 47.476 | 83560 | 8356 |
| 32 | 55.121 | 97010 | 9701 | 46.973 | 82670 | 8267 |
| 33 | 55.130 | 97030 | 9703 | 46.457 | 81760 | 8176 |
| 34 | 55.138 | 97040 | 9704 | 45.926 | 80830 | 8083 |
| 35 | 55.148 | 97060 | 9706 | 45.380 | 79870 | 7987 |
| 36 | 55.157 | 97080 | 9708 | 44.822 | 78890 | 7889 |
| 37 | 55.166 | 97090 | 9709 | 44.249 | 77880 | 7788 |
| 38 | 55.175 | 97110 | 9711 | 43.663 | 76850 | 7685 |
| 39 | 55.185 | 97130 | 9713 | 43.063 | 75790 | 7579 |
| 40 | 55.194 | 97140 | 9714 | 42.450 | 74710 | 7471 |

| Latitude Degrees N or S | Latitude: 48′ Latitude in Miles | Latitude: 48′ Latitude in Yards | Latitude: 5th Division Grid in Yards | Longitude: 72′ Longitude in Miles | Longitude: 72′ Longitude in Yards | Longitude: 5th Division Grid in Yards |
|---|---|---|---|---|---|---|
| 40 | 55.194 | 97140 | 9714 | 63.676 | 112070 | 11207 |
| 41 | 55.205 | 97160 | 9716 | 62.737 | 110420 | 11042 |
| 42 | 55.214 | 97180 | 9718 | 61.780 | 108730 | 10873 |
| 43 | 55.224 | 97190 | 9719 | 60.803 | 107010 | 10701 |
| 44 | 55.234 | 97210 | 9721 | 59.808 | 105260 | 10526 |
| 45 | 55.243 | 97230 | 9723 | 58.794 | 103480 | 10348 |
| 46 | 55.253 | 97250 | 9725 | 57.763 | 101660 | 10166 |
| 47 | 55.263 | 97260 | 9726 | 56.713 | 99810 | 9981 |
| 48 | 55.273 | 97280 | 9728 | 55.646 | 97940 | 9794 |
| 49 | 55.282 | 97300 | 9730 | 54.563 | 96030 | 9603 |
| 50 | 55.289 | 97310 | 9731 | 53.462 | 94090 | 9409 |
| 51 | 55.302 | 97330 | 9733 | 52.345 | 92130 | 9213 |
| 52 | 55.311 | 97350 | 9735 | 51.211 | 90130 | 9013 |
| 53 | 55.321 | 97360 | 9736 | 50.063 | 88110 | 8811 |
| 54 | 55.330 | 97380 | 9738 | 48.899 | 86060 | 8606 |
| 55 | 55.340 | 97400 | 9740 | 47.719 | 83990 | 8399 |
| 56 | 55.349 | 97410 | 9741 | 46.525 | 81880 | 8188 |
| 57 | 55.358 | 97430 | 9743 | 45.317 | 79760 | 7976 |
| 58 | 55.367 | 97450 | 9745 | 44.094 | 77610 | 7761 |
| 59 | 55.376 | 97460 | 9746 | 42.859 | 75430 | 7543 |
| 60 | 55.384 | 97480 | 9748 | 41.609 | 73230 | 7323 |

| Latitude Degrees N or S | Latitude | | | Longitude | | |
|---|---|---|---|---|---|---|
| | 108′ Latitude in Miles | 108′ Latitude in Yards | 5th Division Grid in Yards | 108′ Longitude in Miles | 108′ Longitude in Yards | 5th Division Grid in Yards |
| 60 | 55.384 | 97480 | 9748 | 62.413 | 109850 | 10985 |
| 61 | 55.393 | 97490 | 9749 | 60.521 | 106520 | 10652 |
| 62 | 55.401 | 97510 | 9751 | 58.608 | 103150 | 10315 |
| 63 | 55.409 | 97520 | 9752 | 56.678 | 99750 | 9975 |
| 64 | 55.417 | 97530 | 9753 | 54.731 | 96330 | 9633 |
| 65 | 55.425 | 97550 | 9755 | 52.767 | 92880 | 9288 |
| 66 | 55.432 | 97560 | 9756 | 50.787 | 89390 | 8939 |
| 67 | 55.439 | 97570 | 9757 | 48.791 | 85870 | 8587 |
| 68 | 55.446 | 97580 | 9758 | 46.778 | 82330 | 8233 |
| 69 | 55.453 | 97600 | 9760 | 44.752 | 78760 | 7876 |
| 70 | 55.459 | 97610 | 9761 | 42.712 | 75170 | 7517 |
| 71 | 55.466 | 97620 | 9762 | 40.660 | 71560 | 7156 |
| 72 | 55.472 | 97630 | 9763 | 38.594 | 67930 | 6793 |
| 73 | 55.478 | 97640 | 9764 | 36.517 | 64270 | 6427 |
| 74 | 55.483 | 97650 | 9765 | 34.429 | 60600 | 6060 |
| 75 | 55.488 | 97660 | 9766 | 32.328 | 56900 | 5690 |
| 76 | 55.493 | 97670 | 9767 | 30.218 | 53180 | 5318 |
| 77 | 55.498 | 97680 | 9768 | 28.100 | 49460 | 4946 |
| 78 | 55.502 | 97680 | 9768 | 25.970 | 45710 | 4571 |
| 79 | 55.506 | 97690 | 9769 | 23.836 | 41950 | 4195 |
| 80 | 55.509 | 97700 | 9770 | 21.692 | 38180 | 3818 |

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